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# THE PRINCIPLES AND PRACTICE

AND

# EXPLANATION OF THE MACHINERY

OF

# LOCOMOTIVE ENGINES

## IN OPERATION ON THE SEVERAL LINES OF RAILWAY:

EXEMPLIFIED IN THE EXAMPLES CONSTRUCTED BY

BURY, CURTIS, AND KENNEDY, LIVERPOOL.
T. R. CRAMPTON, LONDON.
D. GOOCH, GREAT WESTERN RAILWAY.
R. AND W. HAWTHORN, NEWCASTLE-UPON-TYNE.
J. SAMUEL, EASTERN COUNTIES RAILWAY.
SHARPE BROTHERS AND CO., MANCHESTER.
R. STEPHENSON AND CO., NEWCASTLE-UPON-TYNE.
E. TAYLEUR AND CO., WARRINGTON.

**With Descriptive Text.**

TO WHICH ARE ADDED

RULES AND REGULATIONS FOR THE PRACTICAL MANAGEMENT OF A LOCOMOTIVE ENGINE, WITH EXPERIMENTS ON THE RESISTANCE OF RAILWAY TRAINS, BY J. SEWELL, GREAT WESTERN RAILWAY.
THE DIMENSIONS OF THE LOCOMOTIVE ENGINE BOILER IN RELATION TO ITS EXPANSIVE POWERS, BY R. ARMSTRONG.
THE CONSUMPTION OF FUEL AND THE EVAPORATION OF WATER, BY E. WOODS, LIVERPOOL.

COMPLETING DIVISION A.

AND FORMING THE FIRST VOLUME OF THE NEW EDITION
OF
TREDGOLD ON THE STEAM ENGINE.

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# ADVERTISEMENT.

In the reproduction of **Tredgold's** universally esteemed Work, it becomes indispensably necessary to supply the additional information derivable from recent improvements in the machinery of the Locomotive Engine, and to illustrate, by elaborate engravings, the several Examples constructed by the most eminent Engineers since the publication of the preceding edition;—to place on record the results of Experiments which have been made with a view to ascertain the Resistance to Railway Trains, the Consumption of Fuel, Evaporation of Water, &c.; and to give publicity to the Rules and Regulations which have been suggested and adopted for the Practical Management of Engines and Trains.

To the Gentlemen who have liberally contributed the Papers and Drawings which comprise the first Division of the Work, the Publisher embraces this opportunity of returning his grateful thanks, and of expressing his regret that Messrs. R. Stephenson and Co.'s newest patented locomotive is not noticed in the present volume, more especially as Mr. Robert Stephenson had readily acceded to his application on the subject.

By some mischance, however, the drawings for this engine were not received until many of the Subscribers had expressed their anxiety for the completion of the volume; and although it is now reluctantly thus closed, it is hoped that the contents will afford abundant information for every practical purpose. The

Illustrations are of a superior kind, and no expense has been spared to render the volume an acceptable addition to the library of the Engineer and the Mechanic.

By the arrangement adopted, namely, the publication of the present edition in separate Divisions, as specified on the wrapper of each Monthly Part, it will be obvious that the Publisher has been actuated by an earnest desire to consult the interests of his numerous Subscribers; and that neither the Railway Engineer nor the Locomotive Machinist will thus be unnecessarily burdened with subjects unconnected with his own professional pursuits. Similarly, the next Division, devoted exclusively to MARINE ENGINES, will enable the Mariner and Engineer employed in Steam Navigation, to purchase separately that portion only which is more especially applicable to their individual practice.

In the anticipation of continued professional patronage, he has been equally anxious to produce the work on the most moderate terms; and, taking into consideration the outlay for engraving, printing, and paper, together with the addition of editorial and other expenses necessarily incurred in its production, he trusts that the cost of each volume will be deemed unexceptionable.

JOHN WEALE.

March 1, 1850.

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# DIVISION A.—LOCOMOTIVE ENGINES.

FIRST PAPER.

# A COMPLETE SET
# OF
# RULES AND REGULATIONS
# FOR THE
# PRACTICAL MANAGEMENT OF A LOCOMOTIVE ENGINE,
# AND
# FOR THE GUIDANCE OF ENGINE DRIVERS.

BY JOHN SEWELL, L.E.

JOHN WEALE, AUGUST 31ST, 1848.

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## INTRODUCTION TO THE FIRST PAPER.

Locomotive engine driving has now become a very important duty, requiring the utmost vigilance on the part of the driver, which renders it necessary that he should possess at all times great presence of mind and promptitude of action when on the road.

The importance, therefore, of these duties to the public requires a proper course of training and examination before any candidate becomes qualified to act as an engine-man.

For this reason there should be a regular period of apprenticeship for every engine-man, the length of such apprenticeship being regulated by his previous mechanical knowledge and experience. The speed on railways is now about 20 miles an hour greater than it was about ten years ago; and the man who could then, with little training, drive a locomotive at a speed of from 20 to 25 miles an hour, could not be prudently appointed to do so at a speed of from 40 to 45 miles an hour, now common on all lines of railway.

We therefore think that it is only a necessary precaution on the part of Railway Companies, that every engine driver in their employment should have his indentures regularly drawn up and attested in the usual way of such deeds, as they would be alike valuable to the public, to railway companies, and to engine-men, as satisfactory testimonials of experience, competency, and good conduct.

It is, however, highly creditable to engine drivers as a body, that in most cases of emergency they have proved equal to the occasion, and all competent drivers now employed should be entitled to indentures from their present employers.

The plan, therefore, on which the following Rules are drawn up, is "to begin at the beginning," and accordingly they commence with the personal and skilled qualifications and period of apprenticeship. They next embrace pay,—conditions of service,—and premiums for economy and good conduct. The latter is a prudent plan, which works well for the employers and employed. We proceed then to the engine-man's active duties, taking them in rotation as they occur when he is on duty, and including instructions for accidents, fogs, inclines, junctions, tunnels, piloting, and when in shed,—thus closing the cycle of the usual duties of an engine driver, and forming altogether a complete set of Rules, which will be instructive to the public as well as useful to those for whom they are more especially intended.

On extensive railways with numerous branches, special regulations are necessary, such as a lamp or lamps of a particular colour to distinguish particular trains by; the rate of speed; signals, &c., at particular junctions, inclines, or tunnels,—all which can be readily drawn up according to the peculiar circumstances attending each case, from the ample means in the following pages of supplying the necessary details. Many of the Rules are framed upon the suggestions arising from the actual observation of accidents caused by neglect of the precautions conveyed in them during ten years' experience, and they are consequently more comprehensive than those formerly drawn up by Charles Hutton Gregory, C.E.

No rules or instructions can supply the place of proper training, or the want of the requisite mental and personal qualifications of the man; but where these qualifications exist, a set of rules, followed up by a course of training, furnishes a candidate with the experience of others in addition to his own, thus enabling him to carry out the instructions he receives with safety and success.

At the end of the Rules, various useful Tables are given and practically explained, in order to facilitate the calculation of the speed, power, traction, consumption of steam, water and coke of a locomotive, which will be both useful and interesting. Forms are also given of time, coke, mileage, and train tickets, for main as well as branch lines, readily convertible to all lines,—forming altogether a complete Code of Instructions for the Management of a Locomotive Engine.

A Glossary of Terms concludes this Paper; and it only remains to express a hope that it will be favourably received by the profession, by all interested in railways, and by the public.

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Explanation of Tickets.
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# MANAGEMENT

# OF

# THE LOCOMOTIVE ENGINE.

## QUALIFICATIONS OF ENGINE DRIVERS AND FIRE-MEN.

1. Personal.—The most essential personal qualifications of an engine-man or fire-man are,—sobriety, steadiness, activity, presence of mind on emergencies, and the most constant watchfulness when on duty. These, combined with an accurate practical knowledge of the construction of a locomotive engine and its management, are essentially necessary to any candidate before he can become a good and safe engine driver. The same qualities of mind, combined with a knowledge how to shut off and put on steam, reverse the engine, know the height of the water in the boiler, how to turn on the feeds, and apply the brakes, are necessary for every candidate before he can be allowed to go with a train as fire-man.

2. Skilled.—Every engine-man and fire-man should be able to read and write, and understand the mechanism of a locomotive engine. If they have been fitters of engines, it is by some regarded as an advantage, and should be so stated in their testimonials.

3. Apprenticeship.—Every engine-man should serve a regular apprenticeship. If the candidate has been a fitter or erecter of locomotives, or a stationary engine driver of experience, he must serve as fire-man at least one year, under a steady and competent engine-man, who must certify to his steady habits and practical knowledge of the principles of the management of an engine before the candidate is qualified to become an engine driver. If he has not been a fitter, erecter, or a qualified stationary engine driver, the candidate must serve three years as a fire-man, to the satisfaction of the locomotive superintendent, and also obtain the certificate of the engine-man (as above) before he is qualified to become an engine driver.

4. Examination.—When the candidate has served his appointed time as a fire-man, he must deliver the engine-man's certificate of his knowledge, sobriety, and good conduct, to the locomotive superintendent, who will then, in presence

of the engine-man he served under, personally examine the candidate as to his knowledge and competency to manage a locomotive in cases of emergency, and otherwise of his several duties as a driver. If the candidate pass this examination satisfactorily, he will then be eligible to act as an engine-man whenever his services may be required.

5. INDENTURES.—The indentures, testifying to the candidate's knowledge, competency, sobriety, regular habits, and that he has passed his examination successfully, should then be signed by the locomotive superintendent, as expressive of his confidence in the general ability of the candidate to be appointed a locomotive engine driver. This indenture should be deposited with the Secretary or other officer appointed to take charge of such documents, who will restore it to the owner, with an additional testimonial of good conduct, upon his leaving the service in a proper manner.

## PAY AND CONDITIONS OF SERVICE.

6. EXCLUSIVE SERVICE.—Every man must devote himself exclusively to the Company's service, attending at such hours as may be appointed, and residing wherever he may be required.

7. OBEDIENCE.—He must obey promptly all instructions he may receive from the locomotive superintendent, or other persons placed in authority over him by the Directors, and must strictly conform to all the regulations of the Company. Every engine-man and fire-man will be under the immediate orders of the locomotive superintendent, or his foreman, when not with a train; and they must obey all their orders, in addition to the general Rules and Regulations with which they are furnished.

8. PAY AND PREMIUMS.—The pay is usually fixed per week, and for such hours, whether early or late, as the working of the line requires; the general principle being to give to every engine-man a fair day's work.

When off duty on the line, the engine-man will be employed in the engine-shed on his own engine, if it require it, or otherwise as instructed by the foreman of the engine-house. On some of the leading lines, premiums are given for good conduct, and for economizing the consumption of coke and stores, which is found to work very well, and might be usefully extended on all lines.

9. MISCONDUCT.—He will be liable to immediate dismissal for disobedience of orders, negligence, misconduct, rudeness, incompetency, or insobriety; and to fines, for other errors, as may be determined by the Directors of the Company.

Intoxication being a grave offence, every man so offending, besides dismissal, will be liable also to fine and imprisonment by the magistrates of the district. If dismissed for any serious fault, or if quitting the Company's service without the usual notice, the whole or any part of the arrears of his pay, then due, will be forfeited, as may be determined by the Directors.

10. Deductions.—The Company reserve the right to deduct from the pay of their men such sums as may be awarded as fines for neglect of duty, and for rent, when engine-men or fire-men are their tenants.

11. Absence.—No engine-men or fire-men must absent themselves from their duty without the permission of their superior officer, as the pay of every man absent without leave, or from sickness or other cause, will be suspended until a special order is obtained in each case from the Directors.

12. Dress.—Every engine-man and fire-man to appear in white fustian clothes, which are to be neat and clean every Monday morning, or on Sundays, when they may be required to work on that day.

### DUTIES OF ENGINE-MEN AND FIRE-MEN.

13. Discretion.—As every engine-man must serve an apprenticeship to engine driving, and pass his examination before he obtains charge of an engine, it would be as unnecessary as it is impossible to lay down rules for every contingency which may occur to an engine on the road, as they require that presence of mind, discretion, and cool promptitude of action from the engine-man, which can only be obtained by experience.

The following Rules and Instructions contain, however, the principal points of practical engine driving and engine-men's duties, as adopted on the leading railways of the country.

14. Attendance.—As it is an important part of an engine-man's duty to examine his engine, and see that it is in a proper state for work before leaving the shed, he should be in attendance at least one hour previous to his time of starting, as fixed by the locomotive superintendent for each man, and the fire-man at least one hour and a half before that time.

15. Examination of Engine.—The engine-man is held responsible that his engine is in good working order before it leaves the engine-house, and that his lamps are properly trimmed when he receives them, and that they are put in their places; and also that he has a sufficient supply of both coke and water in his tender. Before starting, therefore, he must carefully inspect all the connecting-rod cotters, set-pins, and split-pins of all parts of his engine; also see that the stuffing-boxes are properly packed, try his pumps and feed-pipes, as he moves out of the shed, and examine all the wheels, axles, and brakes, so far as he can do so; and if on this inspection he should discover any thing wrong, he will

at once report it to the foreman on duty, that another engine may be provided to take the train.

16. Oiling.—The engine-man must examine and fill up all the oil and tallow cups and boxes on every part of his engine before he leaves the shed, and at the same time see that the syphon cotton, or worsted, is clean, and will feed the oil, so that every working part may be regularly supplied with oil, to prevent axles, connecting-rod bearings, eccentric straps, or slide motion, from becoming heated. From the rapid movement of these parts, they require frequent attention during the trip and at stopping stations.

17. Tools.—Every engine-man must have with him at all times the following tools, for which he will be held responsible; and any person found guilty of concealing or destroying tools not under their own charge, will be fined or dismissed, as the case may require.

1 set of signal lamps.
1 gauge and 1 hand lamp.
1 set of screw-keys.
2 monkey wrenches.
2 clack drawers.
2 set-screws for slide-rods.
1 top and 1 bottom clack.
2 syphon cups.
1 rough and 1 smooth half-round file.
3 cold chisels.
1 padlock and chain for tools.
1 hand hammer.
1 plug hammer.
1 tube plug driver.
6 tube plugs.
1 pinch-bar.
2 tapered bars, 2″ × 1″ (for rails).
1 coke shovel.
2 coupling chains and hooks.
2 coupling links.
12 spare pins and cotters.
1 half-in. round rod, 3 ft. long (for steam chest).
1 screw-jack.
1 set of fire irons.
2 fire buckets.
1 set of oil cans.
1 set of oil fillers.
1 oiling tube.
Some cord, flax, spun-yarn, and rope.
Detonating signals.
Torches for tunnels and night.

18. Tickets.—Each engine-man, before going out with his train, must procure, from his foreman's office, a train and coke and mileage ticket, to be filled up by him in the following manner: First, the exact time at which the train is started; second, the number and description of the carriages in the train; and upon arriving at the end of his trip, he must enter the time of his arrival, with any remarks he may have to make upon his trip, such as being assisted by another engine, how far assisted, and, if late, the cause of the delay.

On the coke and mileage ticket he must enter the number of trips he runs, the names of the stations between which they are run, and the number of miles; also the time his engine stands as a pilot. On this ticket must also be entered the weight of coke he receives during the day, attested by the signature of the coke-man where it is received; the engine-man, in turn, signing the coke-man's book for the quantity he received. Great attention should be given that these tickets are properly filled up, as they exhibit very accurately the performances of the engines, when carefully made up by each engine-man. Neglect of proper entries should be punished by a small fine.

19. Time Bill.—Every engine-man must take his time table with him, and regulate by it the speed of his engine as he proceeds; the great object being to keep the train going at the speed required, from which he should vary as little as possible, in order that he may arrive at all the stations as punctually to the time as is practicable. (For forms of all these Tickets see end of Rules.)

20. Whistles, when to be used.—The whistle is intended to be used as a signal of attention or of danger, and it must be sounded on approaching stations, level crossings, and tunnels; also, during a fog, snow storm, or violent rain, it must be sounded every quarter of a mile, and likewise for warning any persons who may be on the line of the approaching engine and train. On lines where only one whistle is used, three short sharp whistles, rapidly repeated, is the signal for danger; on other lines, a better description of guard's whistle is used, with a deep tone. When either of these signals is made, the guard must immediately apply his brakes, and do all he can to stop the train.

21. Water and Coke.—The engine-man must take his engine to the water crane, have his tender filled with water, and receive as much coke as will carry him to the next watering and coking station. He must not pass one of these stations without renewing his supply of both coke and water, if he requires it. When steam is blowing off, the hot water cock should be turned on to heat the water in the tender, and he must have a full boiler, and good fire, before he goes to the train.

22. Lamps.—Before dark, or in the evening before it is dusk, or in a fog, the engine-man must see that his lamps are lighted and properly fixed in their places; and if he should have to go out without a train, then he must fix a red lamp behind the tender. Should he be on the line through any unforeseen cause without his lamps, he must procure some from the first principal station he comes to.

23. Going to Train.—The engine-man having assured himself, by a careful examination, that his engine, lamps, tools, and spare stores are all in good order, and obtained his train, coke, mileage and time tickets, must cross over to the main line, in front of the train, five minutes before the time of starting, unless ordered otherwise by some superior officer.

Great caution must be used in placing the engine against the train, which should be done without moving a single carriage, in order to guard against injury to any passenger who may be in the act of stepping into a carriage at that moment.

24. Guards' Orders. — Every engine-man will be under the orders of the first guard of the train in all matters affecting the starting, stopping, or the movements of the train. In cases of accident, he must, if required, disconnect his engine, and proceed for assistance as he may be instructed by the first guard. He

must also give both his advice and assistance to the guard in every way he can in all cases of accident, and generally obey promptly all orders or signals given to him, whether by station masters or the first guards, so far as the safe and proper working of his engine will admit.

25. ENGINE STANDING.—While the engine is standing still, whether before starting, or at a station, or on the line, for however short a time, the slides must always be thrown out of gear, the steam shut off, and the tender brake screwed tight on, until the signal be given for starting. The engine-man must be very careful to start, and stop, steadily, without jerking the train, and not shut off the steam too suddenly (unless in cases of accident), so as to cause a concussion of the carriages, or waggons, to the risk of passengers, and, in cattle trains, to the injury of the animals. He must at no time leave his engine without seeing the above rules strictly complied with, and then not without placing the engine in charge of his fire-man.

26. PERSONS ON TENDER.—Except the proper engine-man and fire-man, no person is allowed on the engine or tender without the permission of the Directors or one of the superior officers of the Company, or in case of need, during the journey, by direction of the first guard of the train.

27. STARTING THE TRAIN.—Every engine-man, on receiving the signal from the first guard to start the train, must sound his whistle BEFORE TURNING ON THE STEAM; then place himself by his hand gear, and very carefully and gradually open the regulator, to prevent jerking of the carriages, slipping, priming, or other injury to his engine. When the engine has got into speed, he must then regulate the travel of his slides, according to the load, and open the regulator to that point, determined by experience, where the generation and consumption of steam take place with greater effect and economy than when the regulator is full open. Nothing should induce the engine-man to use steam of a higher pressure than is allowed by the locomotive superintendent.

28. WATER IN THE CYLINDERS.—The condensed steam in the cylinders must be allowed to escape by the steady and gradual opening of the regulator, and likewise of the cylinder cock, as the sudden opening of the regulator is liable to break the piston or cylinder-cover joints, when there is water in the cylinders.

29. PRIMING.—When priming takes place from the boiler, the steam must be partly shut off, and the fire-door opened, which will generally stop it. But if it arises from the boiler being too full, the feeds must be shut off, to reduce the water to its proper level. When the boiler is not too full, the feeds must not be shut off, in order to save the tubes and fire-box, which would thus become exposed from the rapid waste of water by the priming, if such waste was not kept up by the feeds.

30. SLIPPING.—When an engine begins to slip, the steam must be nearly all

shut off, and carefully regulated until slipping ceases. Engines should have two sand-boxes, which should then be opened, that equal bite may be given to both driving wheels from the sand dropping on the rails. When slipping ceases, the slides of the sand-boxes must be shut off, and the regulator gradually opened to its proper place. A third sand-box is used for backing a train with.

31. FEEDING WATER.—The supply of water to the boiler must be carefully regulated, so as to keep both feeds on at an uniform rate all the way, thereby keeping the boiler at a proper and equal level, for the more rapid and regular generation of steam. When near the end of a trip, the feeds may be gradually increased as shall be required to fill up the boiler, before arriving at the station.

The. feeds should at no time be too suddenly opened, as doing so is very liable to break the clacks.

32. FIRING.—Coke must, as far as possible, be put on the fire at such places as do not require the full power of the engine. The steam must be partly shut off when coke is put on the fire, as, when the steam is full on, the strong draft carries the coke up against the tubes, and is liable to choke them up. When approaching the end of the trip, the small coke must be used, and the fire allowed to burn as low as will take the train on to the station safely.

33. ATTENTION TO SIGNALS.—Every engine-man must keep a good look-out, as he moves forward, for any signals, either from the police or from any other person, or for any indication of danger made to him, or which he may observe himself,—all which he is responsible for seeing and immediately attending to; and he must obey any signal made by a police-man, or gate-keeper, even if he should see reason to think such signal unnecessary. The lives of the passengers are intrusted to his care, and it is fully expected that he shall not only attend to every signal given him, and to all his instructions, but also that he will, on all occasions, be vigilant and cautious himself, not trusting entirely to signals for safety.

34. DESCRIPTION OF SIGNALS.—The usual signals are as follows:

| | | | | | |
|---|---|---|---|---|---|
| *Red,* | as a | signal of | *Danger,* | is | *Stop.* |
| *Green,* | ,, | ,, | *Caution,* | ,, | *Proceed slowly.* |
| *White,* | ,, | ,, | *All right,* | ,, | *Go on.* |

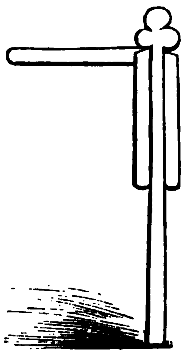
### DETONATING SIGNALS FOR FOGGY WEATHER.

*Semaphore Signals.*—Posts with two moveable arms, standing right and left to the line of rails, which are raised or depressed by a police-man, to denote *danger, caution,* or *all right,* as the case may be.

### LAMP SIGNALS FOR NIGHT.

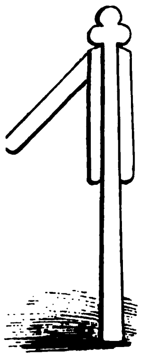
### SEMAPHORE.

Stop.



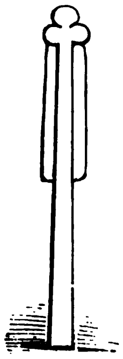
1. Danger.

Go slowly.



2. Caution.

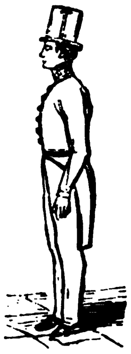
Go on.



3. Right.

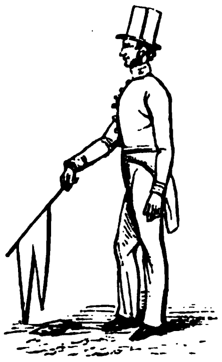
### POLICE.

Go on.



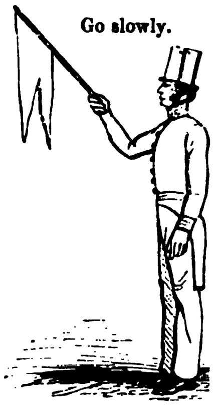
4. Right.

Go slowly.



5. Caution. Bad Road.

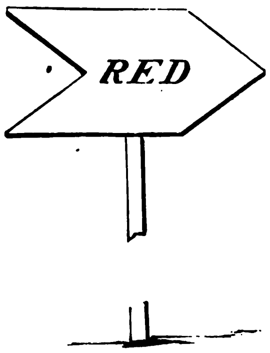
Go slowly.



6. Caution. Engine ahead, on same line.

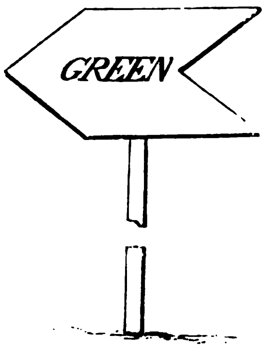
### (Painted Boards.)

Stop.



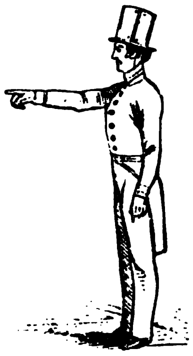
7. Danger.

Go slowly.



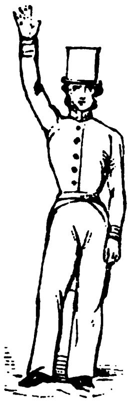
8. Caution.

Go on.



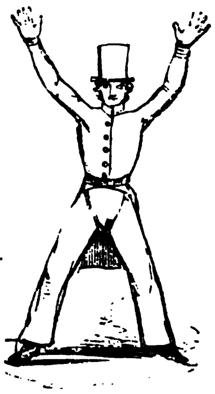
9. Right.

Go slowly.



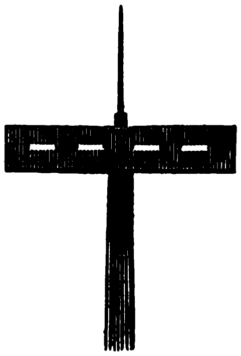
10. Caution.

Stop.



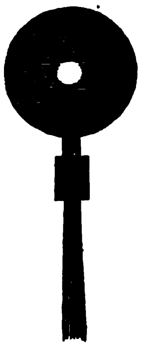
11. Danger.

High Masts.
Stop.

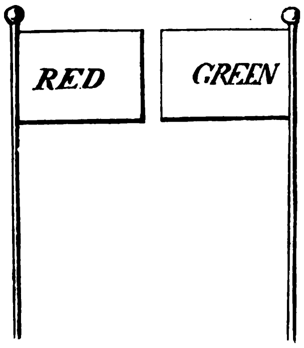


Painted Red.
12. Danger.

Go on.



Painted Red.
13. Right.



14. Hand Signals.
Danger. Caution.

Hand-flags in windy weather are a very bad signal, painted boards being much better, as they always show their full size, whilst the wind not unfrequently makes the hand-flag appear a mere line.

Waving a white light violently is also a signal of danger, when a red light is not to be had. Fog, night, and tunnel signals are made by lamps and detonators. Day signals by police-men, hand-flags, painted boards, and high-mast signals. As signals vary on different lines, each engine-man is supplied with a set of the Rules and Regulations of the Company he is employed by, describing the particular signals used, and which must be strictly attended to on every occasion.

35. Fire-men's Duties.—Fire-men are to be entirely under the orders of the engine-men while on duty. If the engine-man is engaged with any part of the engine, the fire-man must keep on the look-out, and act for the engine-man, and they must never both leave the engine at the same time. The fire-man must at all times stand up and keep a good look-out, when not otherwise engaged in attending to his other duties; and he must, each mile, look back along both sides of the train, to see that all is right, and that the guards are not signalling by hand or lamp to the engine-man. When the fire-man is so engaged that he cannot look back, he must warn the engine-man, who will then do so himself. The fire-man must also be ready, at all times, at a signal from the engine-man, to go to the brake, and, when approaching any station where the engine is to stop, or observing any obstruction on the line, or seeing any signal intimating danger or caution, it is the duty of the fire-man, without waiting for orders, to go to the brake, and to warn the engine-man instantly. Should the engine-man be rendered incapable of doing his duty, whether by accident or otherwise, the fire-man is to take the management of the engine until another driver can be obtained, proceeding with caution, and reporting the circumstance to the first guard at the earliest opportunity.

36. Guards' Signals.—Guards should regularly signal to the engine-man that all is right; but if any thing is wrong, they must give the caution or danger signal. The usual signal from the engine-man to the guards is by three short sharp whistles on some lines; on others, by a deep-toned guard's whistle,—an excellent plan, preventing the liability of any mistake whatever in the use of the whistles. On this signal being given, the guard must instantly signal that it is understood, to the fire-man, who must look back immediately the signal is given by the engine-man, to observe which signal the guard gives. This signal and answer must be made within the first half mile after starting with a goods train, and every two miles afterwards by the guards on the journey. With passenger trains, this signal must be made every mile on the journey; the whistle being used only in cases of need.

37. ENGINE-MEN'S SIGNALS.—Engine-men must also signal one another when on the road, by standing on the right-hand side of the engine, so as to be next each other in passing, and must always do so with the same signals as those used on the line, to indicate whether the line they have passed is clear, or whether there is a train ahead, or any other cause of danger existing.

38. ALL TRAINS TO BE DRAWN.—No engine must pass along the wrong line of road, nor be allowed to propel a train of carriages or waggons; but in all cases it must draw the train after it on the right road, except in case of an engine being disabled on the road, when the succeeding engine may propel the train slowly as far as the first 'shunt' or siding, at which place the said propelling engine shall move past, and take the lead. In case of the road becoming stopped, when it will be unavoidably necessary for an engine to go back on the wrong line, the engine-man must send his fire-man, or some other competent person, back a distance of not less than half a mile before his engine moves, to warn any engine coming in the opposite direction; and the person so sent back must continue to preserve the distance of half a mile between him and the engine, until it gets into the right line again.

39. DISTANCE BETWEEN ENGINES.—All engines travelling on the same line must be kept at least two miles apart, unless expressly required to join on to the preceding train or engine, which the engine-man shall approach with the utmost caution. Such a step can only be justifiable under a pressing necessity.

40. TWO ENGINES WORKING TOGETHER.—When two engines are working together, the second engine-man must watch for and take his signals from the leading engine-man; but should the second engine-man discover any thing wrong with the train, he must blow his whistle to warn the first engine-man, that the two engines may always check and stop together. Engine-men with trains requiring assistance, must in all cases, with passenger trains, allow the assistant engine to go in front, and also with goods trains, where practicable.

41. PART OF TRAIN DETACHED.—When any part of a train is detached, while in motion, care must be taken not to stop the engine or train in front before the detached part is stopped, no matter whether it has become detached intentionally or by accident, to prevent a dangerous collision with the carriages in front, should the latter stop first. Whenever an engine-man finds his engine disconnected from the train by accident or otherwise, he must keep his engine ahead, clear of the train altogether, and in no case pull up his engine until the train has been stopped by the aid of the guards' brakes, when he can move backwards, and couple on to the train in the usual way.

It is the duty of the guard of any intentionally detached part of the train to apply the brake so as to stop at the proper place.

42. Passing Stations.—Every engine-man must be careful when he passes a station, or when the road is under repair, to proceed slowly and cautiously; and he must also do so whenever he sees the *green signal.* He must on no account pass a *red signal,* or any other which he understands to be a signal to stop, but bring his engine to a stand close to that signal.

43. Stopping at the proper Station.—No engine or train of any sort must stop at any but the appointed stations, except only when a signal is given; or in case of accident to any part of the engine or train; or when, in the judgment of the engine-man, it is necessary to prevent accident or collision.

44. Caution in stopping Trains.—Engine-men, in bringing up their trains, must pay particular attention to the state of the weather, the condition of the rails, the length of the train, and whether on a level, an ascending or descending incline, in determining when to shut off the steam, so as to reduce the speed in proper time, and enable them to have the train so completely under their command as to stop altogether, if necessary, before reaching the platform. Stations must not be entered so rapidly as to require a violent application of the brakes, and the use of the carriage brakes must be avoided as much as possible.

45. Running on Main Line.—No engine must ever be moved from any of the stations on to the main line, except when the engine-man is proceeding, at the proper time, to take his place in front of the train. When on the main line, he must never run beyond the limits fixed at each station, without a regular order, filled up and signed by the proper foreman; and he must strictly follow the instructions contained in such order, both as regards the time of starting, and the place and time of returning.

46. Standing on Main Line.—No engine must be permitted to stand on the main line (except under very special circumstances) when not attached to a train; and no engine-man must leave his engine or train, or any part thereof, on the main line, unless there be a competent person in charge to make the necessary signals: neither must any engine cross the line of railway at a station without permission, or run tender foremost, without the orders of the locomotive superintendent, or from unavoidable necessity.

## EXTRA TRAINS.

47. Signal for extra Train.—Whenever a red board, or flag, by day, or an extra red lamp by night, is carried on the last carriage or waggon of a train, it is an indication that a special or extra train is to follow, that the road and stations may be kept clear for it.

48. On Single Line.—To avoid risk of collision on single lines, from the

meeting of another engine, no extra engine, with or without a train, must be allowed to pass along the line without previous notice.

### LUGGAGE TRAINS.

49. Approaching Stations.—Engine-men with luggage trains must approach all stopping places at a speed not exceeding 12 to 15 miles an hour when within a quarter of a mile of the stopping place; and, when necessary, they must signal the guards or brakes-men before they apply the tender brakes.

50. Uncovered Waggons.—Engine-men must refuse to take up luggage waggons if they contain any goods of a nature to take fire from a spark falling amongst them, unless they are properly covered and tied down.

51. Goods Trains into Sidings.—Engine-men of luggage trains must not pass any siding or crossing when there is a passenger train coming in the same direction, due within fifteen minutes, but must remove from the main line to the siding; and generally all luggage, coal, and ballast trains must give way to passenger trains by going into the nearest siding.

### REPAIRING ROAD.

52. Ballasting.—When any ballast train shall stop on the main line to load or unload ballast, or other materials, the engine-man must send a ballast-man back, at least a mile, with a red signal flag, or board, by day, or a red lamp by night; and the man must stand there, on the look-out, until the ballast train has moved off ten minutes, and stop any coming engine or train, and inform them of the position of the ballast train. No ballasting permitted in foggy weather, unless by a special order, or under the most urgent circumstances.

53. Caution for Repairs.—When repairs of the road are going forward, and persons employed on the permanent way have the use of the road, a signal of danger may be given by those persons, either by a red flag or a red lamp; and on observing this signal the engine-man must immediately stop the train.

54. Train of Empties.—Engines running alone, or with a train of empty carriages or waggons, must not exceed a speed of 25 miles an hour without special orders in each case, or from urgent necessity.

### ACCIDENTS.

55. Stoppages.—In case of any accident to the engine or train, causing a complete stoppage, the engine-man, after giving such directions to his fire-man to open the fire-door, rake out the fire, or otherwise, as may be necessary for the

safety of the engine, must immediately seek the first guard of the train, and communicate with him, and receive his directions; and in the absence of the first guard, the engine-man must himself ascertain whether the engine and train are clear of the opposite line, and of any train passing upon it, and, if they do not appear quite clear, remove the passengers from the carriages. He must also send back a guard or his fire-man, or a special messenger, to the next police-man, to stop any trains coming up. If dusk or dark, he must see that the carriage lamps in front, and his engine lamp, all show red lights forward, and the tail lamps, as usual, show a red light backwards.

56. HAND-PUMP.—Whenever, through any accident, an engine has to stand with steam up, the hand-pump must be worked to keep up the water in the boiler, the fire-door opened, the damper shut, and other means used to prevent, as far as practicable, the generation of steam.

57. DETONATING SIGNALS.—Every engine-man should be supplied with detonating signals, which he is responsible to have always ready for use when on duty. When a stoppage occurs in foggy weather, or at night, one of these signals must be placed on the rails, every 200 yards, until the guard, fire-man, or messenger has gone back a mile at least; and at the end of that distance, two of them must be placed on the rails. When any such accident happens in a tunnel, the engine-man should, if required, occasionally hold down the steam-valve, to prevent the noise, and allow orders to be given and heard more readily. If dark, and without a red lamp or detonating signals, the man sent back must make a signal by waving his light up and down violently. If by day, he must signal with the red flag, or board, or hands, and must in all cases remain until relieved by a police-man, or the obstruction has been removed.

58. BOTH LINES STOPPED.—Should the accident stop both lines of rails, then the same precautions must be taken to place the signals on the opposite line of rail to that which the train is on, but in a contrary direction, so that both lines of rails may be protected for at least a mile from the place of obstruction.

59. TRAIN ON FIRE.—Should fire be discovered in the train, the steam must instantly be shut off, and the train brought to a stand. The signals of obstruction or stoppage must then be made to protect the train, and the burning waggon, or whatever it may be, detached with as little delay as possible. Every means must then be used by the guards and engine-man to put out the fire by water from the tender, or by other means, as the necessity of the case may require. No attempt must be made to reach the nearest water crane, if it is more than 800 yards from the place where the fire is discovered, as such a course is likely to increase the damage.

60. BURST TUBE.—If a tube bursts badly, the steam and feeds must both be shut off, and the engine stopped as quickly as possible. A tube-plug must then be

driven into each end of it, and the boiler filled by the hand-pump. As soon as water is seen in the glass, the fire can be got up again, and the hot fire-box will assist in doing so more quickly. As soon as the steam is up, the engine will be enabled to move on again. In most cases it will not be necessary to stop the engine, as the fire-box end can be plugged up when running, and the other end can be plugged at the first stopping station, without delaying the train.

61. Road Obscured.—When the road is obscured by steam (from a burst tube or any other cause), no approaching engine must pass through the steam or smoke until the engine-man has ascertained that the road is clear. If any engine-man see a train stopped or stopping from accident, or other cause, on the opposite line of railway, he must immediately slacken his speed, so that he may pass such train slowly, and stop altogether, if necessary. He must then ascertain the cause of the stoppage, and report it to the next station. He must also, if necessary, stop all the trains between the spot and the next station, and caution the engine-men of the stoppage. He must also render every assistance in his power in all cases of necessity and of difficulty.

62. Broken Clacks.—Should a pump or feed-pipe give way, one pump is generally sufficient to keep up the boiler; but should that one fail also, the engine must be stopped, and the clacks examined. The engine-man will know by his pet-cocks whether it is a top, middle, or bottom clack that is faulty. If a bottom or middle clack, the nut must be unscrewed, the broken clack taken out, one of his spare clacks put in, and the nut screwed on, when he will be ready to start his engine again. If it is the top clack, it can only be repaired when the steam is not up; but unless the middle clack is also bad, the pumps will still work to keep up the water in the boiler.

63. Broken Spring.—When a spring breaks, it will seldom be necessary to stop the engine until it reaches a station, when the side can be raised by moving the other wheels of the engine on to the two wedge-shaped bars, to be laid flat on the rails, which takes the weight off the wheel where the broken spring is, and allows it to be blocked up by one of the wooden wedges: the engine can then be moved off the bars, and proceed with the train. The same operation may be done by the screw-jack, but the first causes least labour.

64. Broken Machinery.—A railway locomotive is made up of two complete engines, working separately, but both attached to a double crank-axle; therefore, whenever a cylinder-cover, piston, connecting-rod, eccentric-rod, quadrant, slides, or any other working part of the engines gives way on the road, which stops the working of one engine, the engine-man must immediately stop, and remove the broken parts, or rods, so as to leave the other engine clear of all obstruction. He must then disconnect the slide of the broken engine, and adjust it so as to cover

both the steam-ports, where he must secure it by tying, if he has no other resource at hand. The best way of fixing the slide is by a set-bolt, fitted into the outside of the slide-rod guide, being screwed tight up against the slide-rod. A set-pin can also be used when a syphon-cup is screwed on the guide, by taking off the syphon, and introducing a screw of the same thread. When this is done, the engine will be able to proceed, working one cylinder only. Should the boiler have been pierced by any of the broken rods, the fire must be immediately drawn, to save the fire-box and tubes, and a competent person sent for the requisite assistance to remove the engine and train.

65. Working with one Engine.—Whenever the engine-man has only one engine in working order, he will still be enabled to proceed with a light or ordinary train to the first pilot station, where the pilot engine will proceed with the train. Should the train be too heavy, he must consult the first guard whether to proceed with part of it, or not, for assistance, and be guided by his instructions.

66. Broken Slide.—When the slide or slide-rod breaks within the steam chest, the engine must be stopped. If the slide is on the front side of the steam-ports, and the exhaust-port open, it should be pushed back through the front slide-rod gland, so far as to cover the ports. When there is no front slide-rod, but a set-bolt in the steam chest cover, by taking out the bolt the slide can be moved through that hole also; and if the slide is on the back, and the exhaust-port open from the front of the slide, it should be pushed forward through the slide-rod gland until it covers both ports. When impracticable to cover all the ports, from a bad regulator, or other cause, or keep the slide over the ports, the connecting-rod must be taken off, and the piston blocked, to prevent its moving by the pressure of the steam against it; when the engine-man can proceed with one engine, as before.

67. Hot Connecting-rod Bearing.—When the large end of the connecting-rod becomes very hot, the bearing and the crank then adhere to each other at the surface, and at each turn of the crank it tears away the solid metal, to the great danger of breaking the straps, keys, or even the rod itself, and thus leading to most extensive damage to the slide motion, piston, and cylinder, if not to the boiler also. When it cannot be cooled while running, by throwing water upon it, and using oil and tallow to prevent adhesion of the metals, the engine must be stopped, the rod taken off, the slide fixed over the ports, and the engine-man can then proceed, according to circumstances, with one cylinder, as before, until relieved by the first pilot engine. In most cases the engine-man, by reducing his speed, and carefully cooling and oiling the hot bearing, will be enabled to proceed until he comes to a stopping station. If by this heating, or by any other means, an eccentric becomes loose, it must be shifted back to its place as marked on the axle, and screwed fast again.

68. Hot Axle Bearing.—When an axle bearing becomes very hot, the train must be stopped, and the box cooled by water from the tender. The oil or grease-holes must then be cleared, and the box filled up with tallow and oil, which, by renewing at each stopping station, will usually carry the engine, tender, or carriage, safely to the end of the trip. However, should the means used to cool the bearing not succeed, the engine-man must stop at the first pilot station, and allow the pilot engine to take his train.

In most cases it will not even be necessary to stop the train until it reaches a station, when the bearing can be cooled, and the box filled as above.

69. Broken Leading Axle.—When a leading axle breaks, the engine must be stopped, the fire drawn, and assistance obtained to clear the road and forward the train. If the engine is off the rails, the first object is to clear the way for the train to proceed, the engine being got on afterwards.

70. Going off the Rails.—When both engine and tender are thrown off the rails, it is a work of time to get them on again; and the fire must be dropped, and water run off to lighten the engine and save the boiler. Assistance must then be obtained to clear the line, if obstructed, and to forward the train to its destination. After this has been done, the engine and tender must be separated, and got on to the rails separately, by raising them, by means of screw-jacks, until a temporary railway can be laid from under the wheels on to the main line. By this means they may be gradually drawn or pushed on to the road again, according to the position they are placed in.

71. Broken Crank.—When a crank-axle breaks very badly, the engine must be stopped, the connecting-rod taken off, and the slide fixed over the ports, (as Rule 64.) If it is broken at the side of the bearing for the connecting-rod, and the stay bearings are good, the engine-man will still be able to go on with the train, if a light one; or seek assistance, if it is a heavy one. If the crank is so broken that the other engine cannot work, then the fire must be drawn, and assistance obtained in the usual way.

72. Broken Trailing Axle.—When a trailing or hind axle breaks, the engine must be stopped, and the springs and axle-boxes blocked up, so as to keep the wheels as upright as possible. The ends of the axle must then be suspended at a proper height to the foot-plate by a rope, when the engine can proceed with the train, cautiously, until relieved by a pilot engine.

73. Broken Wheel or Tire.—When a wheel or tire breaks, the engine must be stopped, and assistance obtained to forward the train. If it is a driving wheel tire, the wheel must be lifted up by the screw-jack, and blocked up to the proper level, when the engine will be able to move itself, if not the train, out of the way. If it is a leading wheel, or tire of a four or six-wheeled engine, it may

probably be thrown off the rails, and, after the train has been forwarded, the engine must be got on to the rails again, as described in Rule 70.

74. APPREHENSION OF DANGER.—In case of the stoppage of either line of rail from any cause, or apprehension of danger, whether in foggy weather or otherwise, the police-man on duty must place a detonator on the line or lines of rails so obstructed, every 200 yards from the point of danger, until they are protected for at least a mile.

75. CAUTION TO STOPPAGE SIGNALS.—In all these, or any other accident causing a stoppage, due care must be taken that the signals for a stoppage are immediately attended to, in order to prevent any following train coming into collision with the one which has stopped.

## FOGS.

76. CAUTION AT STATIONS.—During a fog, when an engine or train stops at a station, some person must be sent back half a mile, and place a detonating signal on the rail, to stop any engine or train coming up, until the other has started from the station. Detonating signals must also be used in a similar manner whenever any engine or train is following too closely upon another engine or train, or in any case of emergency or of danger.

77. ATTENTION TO DETONATORS.—Whenever an engine passes over one of these signals it explodes with a loud report, and the engine-man must then immediately stop the train. The guards of that train must likewise protect it, by sending back and placing these signals every 200 yards, as before, until they have extended a mile from the train.

78. REMOVAL OF DETONATORS.—After the obstruction is removed, the police-man, guard, or fire-man, must remove all the signals from the rails before proceeding.

79. DISTANCE BETWEEN ENGINES.—No engine or train must leave a station, during a fog, less than ten minutes after any preceding engine or train; and the police-man on duty must give the engine-man the exact time when the train started, and where it is next to stop.

80. CAUTION FOR SIGNALS.—Engine-men must always exercise great caution in foggy weather, and especially in approaching stations, from the difficulty of discerning the regular signals until close upon them; and they must be prepared to bring their engines to a stand before reaching the signal, whenever it is required.

## DESCENDING INCLINES.

81. Attention to Brakes.—In descending inclined planes, engine-men, firemen, guards, and brakes-men, must take care that they have complete control over the speed of the trains, by having the brakes screwed up so far as to be able, by a single turn of the handle, to apply them forcibly to the wheels, when required to do so. The engine-man must not, however, place too much dependence upon the assistance he may get from the carriage brakes, but keep the train perfectly under his own control by shutting off the steam in time.

82. Speed.—No engine or train should descend a steep incline at a greater speed than from 20 to 30 miles an hour, unless by special orders. With very heavy trains, the speed should not exceed 20 to 25 miles an hour; and no attempt should be made to make up lost time in going down an incline.

The usual speeds down inclines from 1 in 80 to 1 in 100, are from 20 to 30 miles an hour, according to circumstances. On inclines from 1 in 37 to 1 in 80, they vary from 10 to 20 miles an hour. At the Wapping Tunnel, Liverpool, the speed is only 4 to 5 miles an hour.

## ASCENDING INCLINES.

83. Dividing Trains.—When inclines are so severe as to require the train to be divided, and taken up at twice, it must be done in the following manner: The part of the train to be left must be pushed into the siding at the bottom of the incline, clear of the main line; the first part must then be taken up the incline, and placed in the siding at the top. The engine or engines will then cross over to return on the proper line for the second part of the train. When this is taken to the top of the incline, it must be left on the main line, clear of the siding, and the first part of the train taken out and coupled to it: by this means the waggons will be again in their proper positions in the train.

Great care must be taken that the last portion of the train is not allowed to run down the incline after the engine is uncoupled from it.

84. Overtaking divided Trains.—In the event of any waggons being left upon the main line at the foot of any incline, and a succeeding engine coming up, such engine must not commence propelling or drawing the said waggons until the engine which left them shall have returned, to take them away.

85. Returning on right Road.—The assistant engine must invariably return down the proper line, and must always stand at the proper place, ready with the tender well supplied with coke and water, having the steam up, and the front of the engine towards the incline.

86. Assisting Passenger Trains.—When a passenger train requires assistance up an incline, the train must be stopped, and the assistant engine coupled on in front of the train engine, and both work together up the incline; and when fairly clear of the incline, the assistant engine must be uncoupled from the train engine, and proceed ahead to the first crossing, where it will pass over to return on the right line to its station at the bottom of the incline.

87. Assisting Goods Trains.—When a goods train requires assistance, it is usually given behind, as it takes a great part of the weight off the front waggon drag-chains; and, in the event of any of the drag-chains giving way, prevents these waggons from descending the line, which they would do, without any check or control, if the engine were ahead.

Great care must be taken by the assistant engine-man behind, to prevent any over-pushing of his engine, in case any waggon break down between him and the other engine. It is best when all assistance can be given ahead of the train.

88. Caution to Pilot-man.—In moving out of the siding to assist a goods train up an incline, the pilot engine-man must take great care that the train is past, before he comes near the main line, so as not to strike the train sideways before it passes clear of the pilot engine. As soon as it is past he must move out, and approach the end of the train with great caution, so as not to run against it with any force, and must give instant attention to any signal from the leading engine-man.

89. Responsibility of Engine-man.— No engine-man should attempt to ascend, without assistance, any incline with a greater load than his engine is quite capable of taking up with certainty; and as this varies very much with the state of the weather, the gradients, and the rails, the engine-man must decide for himself, in each case, whether he requires assistance or not, and act accordingly.

## EXTRA INCLINES.

90. Brakes-men.—When trains arrive at very steep inclines, either in or out of tunnels, such as those on the London and North Western Railway, where stationary power is used to drag them up the incline, or such as the Lickey incline on the Birmingham and Bristol Railway, they are placed under the charge of special brakes-men, who have instructions, in each case, and which they must strictly attend to, both as to the speed, number of carriages or waggons, according to the nature of the traffic to be taken up or down these inclines.

91. General Regulation.—As a general rule, no train is allowed to go

up or down without one of these brakes-men, whose duty it is to examine all the brakes, and satisfy himself that they are in proper order, with sufficient men to work them, before he starts a train either to go up or down one of these inclines. The speed is usually limited from 4 to 10 miles an hour, according to circumstances, and the brakes-men must at all times, whether going up or down, be sure that they have the train under perfect control with the brakes, in the event of any thing giving way.

## TUNNELS.

92. Approached cautiously.—All tunnels must be approached cautiously; so that if a signal is made to stop, the train may be stopped before entering the tunnel. Every engine-man must use his whistle before entering and while passing through a tunnel, to give proper notice to the police-man at the entrance, and to any man who may be employed in the tunnel.

93. Stoppage in Tunnels.—When an engine or train breaks down in a tunnel, the torches must be lighted to ascertain the nature and extent of the accident, which must then be remedied according to instructions in preceding Rules. Great care must be taken to protect the line both ways, to prevent collision and injury to the men at work, until the line is cleared and the train forwarded.

## JUNCTIONS.

94. Signals.—In approaching junctions, every engine-man must blow the whistle at least a mile from the junction, and continue to do so until the police-man in charge of the junction points gives the proper signal that the main line is clear, when the engine-man can proceed on to it with the engine or train at a speed not exceeding from 5 to 8 miles an hour. If, however, the signal be given that the main line is obstructed, then the engine-man must immediately stop the engine or train until the obstruction be removed, and the 'all right' signal be shown, when he can proceed slowly on to the main line, as before.

95. Approached cautiously.—Every engine or train must approach the junction of two lines with great caution, and at a very slow speed, so as to stop altogether before reaching the junction, if necessary. In foggy weather the engine-man must bring the engine or train to a stand before arriving at the junction, and not go on to the main line until he has learned from the police-man on duty how long the preceding train has passed, and he must stop or proceed, according to the information he receives.

## REPORTS.

96. **State of Engine, &c.**—The engine-man must examine his engine at the end of his trip, in the same manner as he did before starting, and report to the foreman on duty, or his clerk, any thing he may observe or know to be wrong, and enter the particulars in the report-book kept for that purpose. He must also report every unusual circumstance which may have taken place on the journey, in the same manner.

97. **Spare Stores replaced.**—Every engine-man must have replaced, before starting with his train, any spare stores he may have used, and he must have any broken tools made good again. He must also see that his lamps are taken to the appointed place to be cleaned and trimmed again.

## DUTIES IN SHED.

98. **Regulation of Weight.**—The weight of every engine should be properly distributed on the wheels and springs. No engine can run steadily with one, two, or three tons more weight upon one spring than upon the opposite one. A six-lever weighing machine should be on all extensive railways for this purpose, by which the weight on each wheel can be regulated with great nicety. For passenger train engines, there should be nearly as much weight on the leading as on the driving wheels. Eight-wheeled engines have more weight on the two leading than on the driving wheels. All the weight required on the driving wheels is as much as to produce sufficient adhesion, in ordinary cases, to draw the train, as there are times when all the weight would not prevent slipping. For all ordinary trains, the engine will run the whole distance in less time and more steadily with lightly loaded driving wheels; for any time lost in starting is more than made up afterwards by the ease given to the machinery. Four and six-wheeled coupled engines have generally all the weight brought into action for power, and not for speed; and it is therefore more equally distributed over the wheels.

99. **Hand-Pump to be tried.**—Every engine-man, when in the shed, should try his hand-pump, to insure himself that it is in good order, as, being seldom required, they are liable to become 'furred up' with the deposit from the water, and in that case of no service in any emergency.

100. **Cleaning Boiler.**—The boiler should be regularly blown out, over the pit provided for that purpose, at such times as the state of the water requires, which the engine-man can readily determine from experience. The boiler must also be washed out with cold water, at least once a week, to remove all loose

deposit from it. Muriate of Ammonia is now used for preventing the adhesion of deposit to the boiler, which it effects by keeping the lime in solution, and which is blown out two or three times a week, according to the purity of the water used for the generation of the steam.

101. Adjustment of Machinery.—Every engine-man, when in the shed, must carefully examine his engine; and, when necessary, adjust the pistons, slides, connecting-rod bearings, axle bearings, springs, or any other part requiring adjustment, and see that the eccentric sheaves are all fast in their right places.

102. Trimming Stuffing-Boxes and Syphons.—He must also pack his stuffing-boxes, examine his clacks and feed-pipes, clean and trim his syphons, so that he may have his engine in good working order when required to go on duty again.

## PILOTING.

103. Tools.—Pilot engine-men must at all times during the hours appointed for them to pilot, stand ready to start at once, with their steam up, their tender full of coke and water, and be provided with the following tools; namely, two pinch-bars, two screw-jacks, a large drag-chain, a rope, two signal lamps, two hand lamps, and detonators. One of the signal lamps to be put on the front of the engine, and the other behind the tender; and the hand lamps to be used as signals, or as may be required.

104. Orders.—When it is necessary to send the pilot engine to look for a train, a regular order must be made out for it; and if at or near to night, both lamps must be lighted, and a red light shown behind, and a green one in front. When the pilot engine-man meets with the train, if it be at a stand, he must ascertain the cause, show red lights both ways, and run on to the next crossing ahead. He must then cross, returning to give every assistance he can, whether the engine be broken down, or any part of the train be off the line, or to push the train slowly before him until he can put it into a siding, and get in front of it, which he must do on the first opportunity.

105. Caution on crossing Line.—No pilot-man in search of a train, past-due, must cross on to the main line until the danger signals are turned on, and then only when he has ascertained from the police-man on duty that he can do so with safety, to prevent collision in case of the train coming up at the moment of crossing.

106. Orders Countersigned.—When any pilot engine is sent out, on its arrival at the next pilot station the engine-man must show his order to the

foreman on duty at such station, and either obtain a fresh order, or have the old one countersigned by the foreman, before he proceeds further.

107. Speed.—Any engine-man proceeding along the line with an order must be careful to proceed at the same average rate of speed as the passenger trains, and on no account to run his engine at a higher speed at any part of his journey, unless otherwise specially instructed in his order.

108. Assistance.—If both lines are obstructed, he must assist in clearing the lines, and then receive instructions for his further movements from the first guard or his superior officer, being careful not to return on the wrong line until he has satisfied himself that the police have been made aware of the circumstance for the whole distance he has to go on the wrong line; and he must then proceed slowly, sounding his whistle every quarter of a mile during the whole time.

109. Responsibility.—When any engine is sent on the line with an order, without any train, or from any other cause without a guard, the engine-man will be entirely responsible for all the movements of the engine; and in addition to the precautions and rules ordinarily applying to him, he must, in the event of being compelled to stop, send back the fire-man to make all the usual signals, as already described for stoppages. The fire-man must not return until he meets and is relieved by the next police-man. If the engine-man is obliged to cross over to the other line, and is some distance from a crossing, he must always move forward on the proper line to the next crossing, and never return on the wrong line.

110. Declaration, to be signed by each man on his appointment.

I, the undersigned, being appointed
in the service of the Company, do hereby bind myself to obey the foregoing Rules and Regulations, as well as such additional rules or instructions as I may receive from time to time. And I hereby declare that the foregoing Rules and Regulations have all been carefully read over to me and fully explained, and that I clearly understand them; that I have received a copy of them, and that I am responsible for any injury to persons or property occasioned by my neglecting the same.

(Signed)

Witness to Signature,

## TABLE I.

*Table of the Time occupied in running ¼, ½, ¾, and* 1 *mile; also the Difference of Time in the Rates of Velocity per mile, and the Speed in feet per minute, of the Engine or Train, from* 1 *to* 90 *miles an hour.*

| SPEED per hour. | TIME OF RUNNING. | | | | Difference of Time per mile. | Speed of Engine per min.* | SPEED per hour. | TIME OF RUNNING. | | | | Difference of Time per mile. | Speed of Engine per min.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ¼ mile. | ½ mile. | ¾ mile. | 1 mile. | | | | ¼ mile. | ½ mile. | ¾ mile. | 1 mile. | | |
| Miles. | Seconds. | Seconds. | Seconds. | Min. Sec. | Sec. | Feet. | Miles. | Min. Sec. | Min. Sec. | Min. Sec. | Min. Sec. | Min. Sec. | Feet. |
| 90 | 10 | 20 | 30 | 40 | | 7920 | 45 | 20 | 40 | 1 0·0 | 1 20 | 1·74 | 3960 |
| 89 | 10·11 | 20·22 | 30·33 | 40·45 | ·45 | 7832 | 44 | 20·45 | 40·90 | 1 1·35 | 1 21·81 | 1·81 | 3872 |
| 88 | 10·22 | 20·45 | 30·66 | 40·9 | ·45 | 7744 | 43 | 20·93 | 41·86 | 1 2·79 | 1 23·72 | 1·91 | 3784 |
| 87 | 10·34 | 20·68 | 31·02 | 41·37 | ·47 | 7656 | 42 | 21·42 | 42·85 | 1 4·28 | 1 25·71 | 1·99 | 3696 |
| 86 | 10·46 | 20·93 | 31·38 | 41·86 | ·49 | 7568 | 41 | 21·95 | 43·90 | 1 5·85 | 1 27·8 | 2·09 | 3608 |
| 85 | 10·59 | 21·17 | 31·76 | 42·35 | ·49 | 7480 | 40 | 22·5 | 45 | 1 7·5 | 1 30 | 2·20 | 3520 |
| 84 | 10·71 | 21·42 | 32·13 | 42·85 | ·50 | 7392 | 39 | 23·07 | 46·15 | 1 9·22 | 1 32·30 | 2·30 | 3432 |
| 83 | 10·84 | 21·68 | 32·52 | 43·37 | ·52 | 7304 | 38 | 23·68 | 47·36 | 1 11·05 | 1 34·73 | 2·43 | 3344 |
| 82 | 10·97 | 21·95 | 32·92 | 43·90 | ·53 | 7216 | 37 | 24·32 | 48·64 | 1 12·97 | 1 37·29 | 2·56 | 3256 |
| 81 | 11·11 | 22·22 | 33·33 | 44·44 | ·54 | 7128 | 36 | 25 | 50 | 1 15 | 1 40 | 2·71 | 3168 |
| 80 | 11·25 | 22·5 | 33·75 | 45 | ·56 | 7040 | 35 | 25·71 | 51·42 | 1 17·18 | 1 42·85 | 2·85 | 3080 |
| 79 | 11·4 | 22·7 | 34·17 | 45·57 | ·57 | 6952 | 34 | 26·47 | 52·94 | 1 19·41 | 1 45·88 | 3·03 | 2992 |
| 78 | 11·53 | 23·07 | 34·71 | 46·15 | ·58 | 6864 | 33 | 27·27 | 54·54 | 1 21·81 | 1 49·09 | 3·21 | 2904 |
| 77 | 11·68 | 23·37 | 35·06 | 46·75 | ·60 | 6776 | 32 | 28·12 | 56·25 | 1 24·37 | 1 52·5 | 3·41 | 2816 |
| 76 | 11·84 | 23·68 | 35·52 | 47·36 | ·61 | 6688 | 31 | 29·03 | 58·06 | 1 27·09 | 1 56·12 | 3·62 | 2728 |
| 75 | 12 | 24 | 36 | 48 | ·63 | 6600 | 30 | 30 | 1 0·00 | 1 30 | 2 0 | 3·88 | 2640 |
| 74 | 12·16 | 24·32 | 36·48 | 48·65 | ·65 | 6512 | 29 | 31·03 | 1 2·06 | 1 33·09 | 2 4·13 | 4·13 | 2452 |
| 73 | 12·32 | 24·65 | 36·98 | 49·31 | ·66 | 6424 | 28 | 32·14 | 1 4·28 | 1 36·42 | 2 8·57 | 4·44 | 2364 |
| 72 | 12·5 | 25 | 37·5 | 50 | ·68 | 6336 | 27 | 33·33 | 1 6·66 | 1 39·99 | 2 13·33 | 4·76 | 2376 |
| 71 | 12·67 | 25·35 | 38·01 | 50·7 | ·70 | 6248 | 26 | 34·61 | 1 9·23 | 1 43·83 | 2 18·66 | 5·13 | 2288 |
| 70 | 12·85 | 25·71 | 38·55 | 51·42 | ·72 | 6160 | 25 | 36 | 1 12 | 1 48 | 2 24 | 5·54 | 2200 |
| 69 | 13·04 | 26·08 | 39·12 | 52·17 | ·75 | 6072 | 24 | 37·5 | 1 15 | 1 52·5 | 2 30 | 6·0 | 2112 |
| 68 | 13·23 | 26·47 | 39·70 | 52·94 | ·77 | 5984 | 23 | 39·13 | 1 18·26 | 1 57·39 | 2 36·52 | 6·52 | 2024 |
| 67 | 13·43 | 26·86 | 40·29 | 53·73 | ·79 | 5896 | 22 | 40·90 | 1 21·81 | 2 2·72 | 2 43·63 | 7·11 | 1936 |
| 66 | 13·63 | 27·27 | 40·90 | 54·54 | ·81 | 5808 | 21 | 42·85 | 1 25·71 | 2 8·55 | 2 51·42 | 7·79 | 1848 |
| 65 | 13·84 | 27·69 | 41·53 | 55·38 | ·84 | 5720 | 20 | 45 | 1 30 | 2 15 | 3 0 | 8·58 | 1760 |
| 64 | 14·06 | 28·12 | 42·18 | 56·25 | ·87 | 5632 | 19 | 47·36 | 1 34·73 | 2 22·08 | 3 9·47 | 9·47 | 1672 |
| 63 | 14·28 | 28·57 | 42·85 | 57·14 | ·89 | 5544 | 18 | 50 | 1 40 | 2 30 | 3 20 | 10·53 | 1584 |
| 62 | 14·51 | 29·03 | 43·54 | 58·06 | ·92 | 5456 | 17 | 52·94 | 1 45·88 | 2 38·82 | 3 31·76 | 11·76 | 1496 |
| 61 | 14·75 | 29·50 | 44·25 | 59·01 | ·95 | 5368 | 16 | 56·25 | 1 52·5 | 2 48·75 | 3 45 | 13·24 | 1408 |
| 60 | 15 | 30 | 45 | 1 0 | ·99 | 5280 | 15 | 1 0 | 2 0 | 3 0 | 4 0 | 15 | 1320 |
| 59 | 15·25 | 30·50 | 45·75 | 1 1·01 | 1·01 | 5192 | 14 | 1 4·26 | 2 8·52 | 3 12·78 | 4 17·14 | 17·14 | 1232 |
| 58 | 15·51 | 31·03 | 46·54 | 1 2·06 | 1·05 | 5104 | 13 | 1 9·23 | 2 18·46 | 3 27·69 | 4 36·92 | 19·78 | 1144 |
| 57 | 15·78 | 31·57 | 47·36 | 1 3·15 | 1·09 | 5016 | 12 | 1 15 | 2 30 | 3 45 | 5 0 | 23·08 | 1056 |
| 56 | 16·07 | 32·14 | 48·21 | 1 4·28 | 1·113 | 4928 | 11 | 1 21·81 | 2 43·63 | 4 5·45 | 5 27·27 | 27·27 | 968 |
| 55 | 16·36 | 32·72 | 49·08 | 1 5·45 | 1·117 | 4840 | 10 | 1 30 | 3 0 | 4 30 | 6 0 | 33·73 | 880 |
| 54 | 16·66 | 33·33 | 49·99 | 1 6·66 | 1·21 | 4752 | 9 | 1 40 | 3 20 | 5 0 | 6 40 | 40 | 792 |
| 53 | 16·98 | 33·96 | 50·94 | 1 7·92 | 1·26 | 4664 | 8 | 1 52·5 | 3 45 | 5 37·5 | 7 30 | 50 | 704 |
| 52 | 17·30 | 34·61 | 51·90 | 1 9·23 | 1·31 | 4576 | 7 | 2 8·57 | 4 17·14 | 6 25·71 | 8 34·28 | 1 4·28 | 616 |
| 51 | 17·64 | 35·29 | 52·92 | 1 10·58 | 1·35 | 4488 | 6 | 2 30 | 5 0 | 7 30 | 10 0 | 1 25·72 | 528 |
| 50 | 18 | 36 | 54 | 1 12 | 1·42 | 4400 | 5 | 3 0 | 6 0 | 9 0 | 12 0 | 2 0 | 440 |
| 49 | 18·36 | 36·73 | 55·09 | 1 13·47 | 1·47 | 4312 | 4 | 3 45 | 7 30 | 11 15 | 15 0 | 3 0 | 352 |
| 48 | 18·75 | 37·5 | 56·25 | 1 15 | 1·53 | 4224 | 3 | 5 0 | 10 0 | 15 0 | 20 0 | 5 0 | 264 |
| 47 | 19·14 | 38·29 | 57·44 | 1 16·59 | 1·59 | 4136 | 2 | 7 30 | 15 0 | 22 30 | 30 0 | 10 0 | 176 |
| 46 | 19·56 | 39·13 | 58·69 | 1 18·26 | 1·67 | 4048 | 1 | 15 0 | 30 0 | 45 0 | 60 0 | 30 0 | 88 |

* For miles and fractions of a mile, multiply the speed given by 88 for the speed in feet per minute.

## TABLE II.

*Table of the comparative Velocity of Pistons to Driving Wheels, the Circumference of the latter taken as* 1.

| Half-travel of Piston in inches. | DIAMETER OF WHEELS IN FEET. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4 | 4½ | 5 | 5½ | 6 | 6½ | 7 | 7½ | 8 |
| * 24 | 0·3182 | 0·2830 | ·2541 | ·2315 | ·2122 | ·1958 | ·1819 | ·1691 | ·1592 |
| 20 | 0·2652 | 0·2393 | ·2122 | ·1929 | ·1768 | ·1632 | ·1516 | ·1414 | ·1326 |
| 19 | 0·2519 | ·2273 | ·2016 | ·1832 | ·1679 | ·1550 | ·1440 | ·1343 | ·1259 |
| 18 | 0·2386 | ·2153 | ·1910 | ·1736 | ·1591 | ·1468 | ·1364 | ·1272 | ·1194 |
| 17 | 0·2254 | ·2034 | ·1803 | ·1640 | ·1503 | ·1387 | ·1288 | ·1202 | ·1127 |
| 16 | 0·2121 | ·1914 | ·1697 | ·1543 | ·1415 | ·1305 | ·1213 | ·1131 | ·1061 |
| 15 | 0·1989 | ·1795 | ·1591 | ·1447 | ·1326 | ·1224 | ·1137 | ·1060 | ·0994 |
| 14 | 0·1856 | ·1675 | ·1485 | ·1350 | ·1237 | ·1141 | ·1061 | ·0990 | ·0928 |
| 13 | 0·1724 | ·1555 | ·1379 | ·1254 | ·1149 | ·1061 | ·0985 | ·0919 | ·0862 |
| 12 | 0·1591 | ·1436 | ·1273 | ·1157 | ·1061 | ·0979 | ·0909 | ·0848 | ·0796 |

*** For every revolution of the driving wheel the piston travels 48 inches; hence for a 7-feet wheel the ratio would be as circumference of 7 ft. = 21·9912 : 4 ft. : : 1 = ·1819, as above. This gives the same result as Tredgold's rule of twice the length of stroke divided by the wheel's circumference = the ratio of the velocity of the piston to the driving wheel.**

## TABLE III.

*Table of Areas of Cylinders or Pistons.*

| Diam. | Area. | Diam. | Area. | Diam. | Area. | Diam. | Area. |
|---|---|---|---|---|---|---|---|
| Inches. | Sq. inches. | Inches. | Sq. inches. | Inches. | Sq. inches. | Inches. | Sq. inches. |
| 10 | 78·540 | 14¼ | 159·485 | 17 | 226·980 | 19¾ | 306·355 |
| 10½ | 86·590 | 14½ | 165·130 | 17¼ | 233·705 | 20 | 314·160 |
| 11 | 95·033 | 14¾ | 170·873 | 17½ | 240·528 | 20¼ | 322·063 |
| 11½ | 103·869 | 15 | 176·715 | 17¾ | 247·450 | 20½ | 330·064 |
| 12 | 113·097 | 15¼ | 182·654 | 18 | 254·469 | 20¾ | 338·163 |
| 12½ | 122·718 | 15½ | 188·692 | 18¼ | 261·587 | 21 | 346·361 |
| 13 | 132·732 | 15¾ | 194·828 | 18½ | 268·803 | 21½ | 363·051 |
| 13¼ | 137·886 | 16 | 201·062 | 18¾ | 276·117 | 22 | 380·133 |
| 13½ | 143·139 | 16¼ | 207·394 | 19 | 283·529 | 22½ | 397·608 |
| 13¾ | 148·489 | 16½ | 213·825 | 19¼ | 291·039 | 23 | 415·476 |
| 14 | 153·938 | 16¾ | 220·353 | 19½ | 298·648 | 24 | 452·390 |

## TABLE IV.

*Tractive Power of Locomotive Engines when the adhesion is from $\frac{1}{5}$th to $\frac{1}{15}$th that of the insistent weight of the Driving Wheels.*

| Insistent weight on Driving Wheels, in tons. | Traction in lbs. when the Adhesion is in the following Ratios. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\frac{1}{5}$ | $\frac{1}{6}$ | $\frac{1}{7}$ | $\frac{1}{8}$ | $\frac{1}{9}$ | $\frac{1}{10}$ | $\frac{1}{11}$ | $\frac{1}{12}$ | $\frac{1}{13}$ | $\frac{1}{14}$ | $\frac{1}{15}$ |
| 5 | 2240 | 1866·6 | 1600 | 1400 | 1244·4 | 1120 | 1018·1 | 933·3 | 861·5 | 800 | 746·6 |
| 6 | 2688 | 2240 | 1920 | 1680 | 1493·3 | 1344 | 1221·8 | 1120 | 1033·8 | 960 | 896 |
| 7 | 3136 | 2613·3 | 2240 | 1960 | 1742·2 | 1568 | 1425·5 | 1306·6 | 1206·1 | 1120 | 1045·3 |
| 8 | 3584 | 2986·6 | 2560 | 2240 | 1991·1 | 1792 | 1629 | 1493·4 | 1378·4 | 1280 | 1194·6 |
| 9 | 4032 | 3360 | 2880 | 2520 | 2240 | 2016 | 1832·7 | 1680 | 1550·7 | 1440 | 1344 |
| 10 | 4480 | 3733·3 | 3200 | 2800 | 2489 | 2240 | 2036·3 | 1866·6 | 1723 | 1600 | 1493·3 |
| 11 | 4928 | 4106·6 | 3520 | 3080 | 2737·7 | 2464 | 2240 | 2053·3 | 1895·4 | 1760 | 1642·6 |
| 12 | 5376 | 4480 | 3840 | 3360 | 2986·6 | 2688 | 2443·6 | 2240 | 2067·7 | 1920 | 1792 |
| 13 | 5824 | 4853·3 | 4160 | 3640 | 3235·5 | 2912 | 2647·2 | 2426·6 | 2240 | 2080 | 1941·3 |
| 14 | 6272 | 5226·6 | 4480 | 3920 | 3484·4 | 3136 | 2851 | 2613·3 | 2412·3 | 2240 | 2090·6 |
| 15 | 6720 | 5600 | 4800 | 4200 | 3733·3 | 3360 | 3054·5 | 2800 | 2584·6 | 2400 | 2240 |
| 16 | 7168 | 5973·3 | 5120 | 4480 | 3982·2 | 3584 | 3280 | 2986·6 | 2756·9 | 2560 | 2389·3 |

## TABLE V.

*Table of Gradients, and Resistance per ton for each Gradient.*

| Vertical Rise. | | Gravity due to incline, per ton. | Vertical Rise. | | Gravity due to incline, per ton. | Vertical Rise. | | Gravity due to incline, per ton. |
|---|---|---|---|---|---|---|---|---|
| Ratio | per mile. | | Ratio | per mile. | | Ratio | per mile. | |
| One in | Feet. | lbs. | One in | Feet. | lbs. | One in | Feet. | lbs. |
| 100 | 52·80 | 22·40 | 74 | 71·38 | 30·270 | 47 | 112·34 | 47·660 |
| 99 | 53·33 | 22·626 | 73 | 72·32 | 30·685 | 46 | 115·04 | 48·684 |
| 98 | 53·88 | 22·858 | 72 | 73·33 | 31·111 | 45 | 117·33 | 49·777 |
| 97 | 54·43 | 23·092 | 71 | 74·36 | 31·550 | 44 | 120·0 | 50·908 |
| 96 | 55·00 | 23·334 | 70 | 75·43 | 32·000 | 43 | 122·78 | 52·092 |
| 95 | 55·60 | 23·579 | 69 | 76·49 | 32·464 | 42 | 125·71 | 53·333 |
| 94 | 56·17 | 23·830 | 68 | 77·64 | 32·940 | 41 | 128·78 | 54·634 |
| 93 | 56·77 | 24·086 | 67 | 78·81 | 33·432 | 40 | 132·00 | 56·00 |
| 92 | 57·52 | 24·342 | 66 | 80·0 | 33·940 | 39 | 135·38 | 57·436 |
| 91 | 58·02 | 24·614 | 65 | 81·23 | 34·460 | 38 | 138·95 | 58·944 |
| 90 | 58·66 | 24·888 | 64 | 82·50 | 35·0 | 37 | 142·70 | 60·540 |
| 89 | 59·33 | 25·168 | 63 | 83·81 | 35·555 | 36 | 146·66 | 62·222 |
| 88 | 60·0 | 25·454 | 62 | 85·16 | 36·108 | 35 | 150·84 | 64·000 |
| 87 | 60·69 | 25·746 | 61 | 86·55 | 36·720 | 34 | 155·30 | 65·880 |
| 86 | 61·39 | 26·046 | 60 | 88·00 | 37·333 | 33 | 160·0 | 67·880 |
| 85·16 | 62·00 | 26·303 | 59 | 89·49 | 37·966 | 32 | 165·0 | 70·0 |
| 85 | 62·12 | 26·353 | 58 | 91·03 | 38·620 | 31 | 170·32 | 72·216 |
| 84 | 62·86 | 26·666 | 57 | 92·63 | 39·298 | 30 | 176·00 | 74·666 |
| 83 | 63·61 | 26·988 | 56 | 94·28 | 40·0 | 29 | 182·06 | 77·240 |
| 82 | 64·39 | 27·317 | 55 | 96·00 | 40·726 | 28 | 188·56 | 80·00 |
| 81 | 65·20 | 27·718 | 54 | 97·77 | 41·480 | 27 | 195·55 | 82·960 |
| 80 | 66·0 | 28·00 | 53 | 99·62 | 42·264 | 26 | 203·06 | 86·152 |
| 79 | 66·83 | 28·355 | 52 | 101·53 | 43·076 | 25 | 211·20 | 89·60 |
| 78 | 67·69 | 28·718 | 51 | 103·52 | 43·920 | 24 | 220·0 | 93·336 |
| 77 | 68·57 | 29·090 | 50 | 105·60 | 44·800 | 23 | 229·56 | 97·368 |
| 76 | 69·47 | 29·472 | 49 | 107·75 | 45·716 | 22 | 240 | 101·816 |
| 75 | 70·40 | 29·867 | 48 | 110·00 | 46·688 | 21 | 251·43 | 106·666 |

## TABLE VI.

*Table of the Revolutions per mile of Driving Wheels, and Consumption of Steam and Water for each sized Wheel; taking the Steam admitted to each Cylinder as exactly* 1 *cubic foot at a gross pressure of* 98 lbs., *or* 83 lbs. *on the Spring Balance.*

**Note.**—As there are two cylinders at work in a locomotive, consequently there are four cylinders of steam for each revolution.

| WHEELS. | | | Cylinders of Steam per mile, and consumption, taking cylinder as 1 cube foot. | Water per mile, taking Steam as 83 lbs. above atmosphere. | WHEELS. | | | Cylinders of Steam per mile, and consumption, taking cylinder as 1 cube foot. | Water per mile, taking Steam as 83 lbs. above atmosphere. |
|---|---|---|---|---|---|---|---|---|---|
| Diameter. | Circumference. | Revolutions per mile. | | | Diameter. | Circumference. | Revolutions per mile. | | |
| Ft. | Ft. In. | No. | Cube ft. | Galls. | Ft. | Ft. In. | No. | Cube ft. | Galls. |
| 10 | 31 5 | 168 | 672 | 14·0 | 6 | 18 9·18 | 280·5 | 1122 | 23·37 |
| 9½ | 29 10⅛ | 176·9 | 707·6 | 14·74 | 5½ | 17 3·33 | 305·6 | 1222·4 | 25·45 |
| 9 | 28 3¼ | 186·7 | 746·8 | 15·55 | 5 | 15 8·48 | 336·3 | 1344·4 | 28·0 |
| 8½ | 26 8⅜ | 197·4 | 789·6 | 16·44 | 4½ | 13 11·1 | 379·0 | 1493·6 | 31·11 |
| 8 | 25 1½ | 210·1 | 840·4 | 17·5 | 4 | 12 6·92 | 420·3 | 1680·4 | 35·0 |
| 7½ | 23 6¾ | 224 | 897·6 | 18·69 | 3¾ | 11 9·37 | 441·1 | 1792·2 | 37·33 |
| 7 | 21 11⅞ | 240 | 960 | 20·0 | 3½ | 10 11·94 | 480·1 | 1920·8 | 40·0 |
| 6½ | 20 5 | 258·6 | 1034 | 21·5 | 3 | 9 5·08 | 560·2 | 2240 | 46·67 |

## TABLE VII.

*Table of the Number of Revolutions of the Driving Wheels, or double Strokes of the Piston, per minute, at the following given Speeds.*

| REVOLUTIONS OF WHEELS, OR DOUBLE STROKES OF THE PISTON, PER MINUTE. | | | | | | | | | Miles per hour. |
|---|---|---|---|---|---|---|---|---|---|
| DIAMETERS OF DRIVING WHEELS. | | | | | | | | | |
| 4 ft. | 4½ ft. | 5 ft. | 5½ ft. | 6 ft. | 6½ ft. | 7 ft. | 7½ ft. | 8 ft. | |
| No. | No. | No. | No. | No. | No. | No. | No. | No. | |
| 210·18 | 189·54 | 168·18 | 152·85 | 140·04 | 129·30 | 120 | 112·02 | 105 | 30 |
| 245·21 | 221·13 | 196·21 | 177·29 | 163·33 | 150·85 | 140 | 130·69 | 122·5 | 35 |
| 280·24 | 252·72 | 224·24 | 203·76 | 186·72 | 172·40 | 160 | 149·36 | 140·0 | 40 |
| 315·27 | 284·30 | 252·27 | 229·23 | 210·06 | 193·95 | 180 | 168·03 | 157·5 | 45 |
| 350·30 | 315·90 | 280·30 | 254·75 | 233·40 | 215·50 | 200 | 186·70 | 175·0 | 50 |
| 385·33 | 347·49 | 308·33 | 280·17 | 256·74 | 237·05 | 220 | 205·37 | 192·5 | 55 |
| 420·36 | 379·08 | 336·36 | 305·64 | 280·5 | 258·6 | 240 | 224·04 | 210·1 | 60 |
| 455·39 | 416·67 | 364·39 | 331·11 | 303·42 | 280·15 | 260 | 242·71 | 227·5 | 65 |
| 490·42 | 442·19 | 392·42 | 356·58 | 326·76 | 301·70 | 280 | 261·38 | 245 | 70 |
| 525·45 | 473·85 | 420·50 | 372·05 | 350·10 | 323·25 | 300 | 280·05 | 262·5 | 75 |
| 560·48 | 505·50 | 448·48 | 407·60 | 373·44 | 344·80 | 320 | 298·72 | 280 | 80 |

## TABLE VIII.

*Table of the comparative Bulk of Water and Steam, from* 14·75 lbs. *to* 200 lbs. *pressure per square inch.*

| Pressure, including atmosphere. | Bulk, water being taken as 1. | Pressure, including atmosphere. | Bulk, water being taken as 1. | Pressure, including atmosphere. | Bulk, water being taken as 1. | Pressure, including atmosphere. | Bulk, water being taken as 1. | Pressure, including atmosphere. | Bulk, water being taken as 1. |
|---|---|---|---|---|---|---|---|---|---|
| lbs. | | lbs. | | lbs. | | lbs. | | lbs. | |
| 14·75 | 1700 | 34 | 788 | 54 | 516 | 73 | 393 | 92 | 319 |
| 15 | 1669 | 35 | 767 | 55 | 508 | 74 | 388 | 93 | 316 |
| 16 | 1573 | 36 | 748 | 56 | 500 | 75 | 383 | 94 | 313 |
| 17 | 1488 | 37 | 729 | 57 | 492 | 76 | 379 | 95 | 310 |
| 18 | 1411 | 38 | 712 | 58 | 484 | 77 | 374 | 96 | 307 |
| 19 | 1343 | 39 | 695 | 59 | 477 | 78 | 370 | 97 | 304 |
| 20 | 1281 | 40 | 679 | 60 | 470 | 79 | 366 | 98 | 301 |
| 21 | 1225 | 41 | 664 | 61 | 463 | 80 | 362 | 99 | 298 |
| 22 | 1174 | 42 | 649 | 62 | 456 | 81 | 358 | 100 | 295 |
| 23 | 1127 | 43 | 635 | 63 | 449 | 82 | 354 | 110 | 271 |
| 24 | 1084 | 44 | 622 | 64 | 443 | 83 | 350 | 120 | 251 |
| 25 | 1044 | 45 | 610 | 65 | 437 | 84 | 346 | 130 | 233 |
| 26 | 1007 | 46 | 598 | 66 | 431 | 85 | 342 | 140 | 218 |
| 27 | 973 | 47 | 586 | 67 | 425 | 86 | 339 | 150 | 205 |
| 28 | 941 | 48 | 575 | 68 | 419 | 87 | 335 | 160 | 193 |
| 29 | 911 | 49 | 564 | 69 | 414 | 88 | 332 | 170 | 183 |
| 30 | 883 | 50 | 554 | 70 | 408 | 89 | 328 | 180 | 174 |
| 31 | 857 | 51 | 544 | 71 | 403 | 90 | 325 | 190 | 166 |
| 32 | 833 | 52 | 534 | 72 | 398 | 91 | 322 | 200 | 158 |
| 33 | 810 | 53 | 525 | | | | | | |

## EXPLANATION OF TABLES.

TABLE I.—Having the velocity given for ¼, ½, or ¾ of a mile,—required the rate of speed per hour? Find the particular velocity or the one nearest to it under the proper column, and opposite to it, in the column 'per hour,' is the rate required.

*Ex.*—If the time in running ¼ of a mile is 16 seconds,—required the rate per hour?

*Ans.*—Under the column '¼ mile' the nearest number is 16·07, and opposite to that number, in the 'per hour' column, is 56 miles, the rate of speed required.

TABLE II.—Having the diameter of the cylinder, length of the stroke, effective pressure of the steam, and circumference of the driving wheel given,—to find the tractive power.

Add together the areas of the two pistons in square inches, and multiply that sum by the effective pressure of the steam on each square inch of the piston. Multiply that product by twice the length of the stroke in inches, which, divided by the circumference of the driving wheel in inches, will give the tractive power of the cylinders in lbs.

*Ex.*—If an engine have driving wheels 6 feet diameter, 16 inches cylinder, 20 inches stroke, with steam at 70 lbs. effective pressure,—required its tractive power?

*Note.*—The diameter multiplied by 3·1416 gives the circumference. The square of the diameter multiplied by ·7854 gives the area.

$$\text{Hence area} = \frac{\overset{\text{Diam.}}{16^2} \times \cdot7854 \times \overset{\text{Pistons.}}{2} \times \overset{\text{Dble. stroke.}}{40} \times \overset{\text{Pressure.}}{70}}{\text{Diam. inches } 72 \times 3\cdot1416} = 4977 \text{ lbs.}$$

Tables No. II. and III. being constructed on these data, shorten the operation; for Table No. II. supplies the co-efficient for the circumference of the wheel and twice the stroke for all the sizes contained in it; and Table No. III. contains the areas of the diameters there given. Table No. VI. contains the circumference in feet and inches of the various sized wheels given in it, which, multiplied by 12, gives the circumference in inches; and this Table may be used when the particular dimensions are not contained in the Table of co-efficients.

*Ex.*—Taking the same dimensions and pressure as last example, from Table No. II., under the heading '6 feet,' and opposite 20 inches, the half-travel or stroke of the piston is ·1768 as the ratio between the piston and driving wheel. From Table No. III., opposite the diameter of 16 inches, is 201·062, its area; hence

$$201\cdot062 \times 2 \times 70 \times \cdot1768 = 4976\cdot68 \text{ lbs.}$$

as the tractive power of the cylinders at that pressure.

The tractive power of the cylinders and the actual tractive power of the engine may, however, be quite different. An engine may have large cylinders with insufficient weight upon the driving wheels, and thus the adhesive traction would be much less than that of the cylinders. The speed of two engines with the same sized cylinders, length of stroke, and driving wheels, may also vary considerably. The boiler being the source of power, that engine which has the largest boiler, and is capable of generating more steam in a minute, will maintain the highest rate of speed, although by the cylinders and size of wheels, theoretically, the powers of the two engines would be the same.

The adhesion of a locomotive engine to the rails is in fine weather about one-fifth the insistent weight on the driving wheels, varying according to the state of the rails up to one-fifteenth, and on some occasions to even less than this, when slipping takes place.

Having the weight upon the driving wheels and the ratio of adhesion given,—to find the actual adhesion in lbs.

Divide the weight in lbs. on the driving wheels by the ratio of adhesion, and the product gives the actual adhesion of the engine. If the weight on the driving wheels is given in tons, multiply them by 2240, which will give the lbs.

*Ex.*—If an engine have 8 tons on the driving wheels, and the adhesion be equal to one-sixth of that weight,—required the tractive power?

$$8 \text{ tons} \times 2240 = \frac{17920}{6} = 2986\cdot6 \text{ lbs. as the tractive adhesion of the engine.}$$

Table No. IV. is drawn up by this rule, where the tractive adhesion in lbs., according to the various weights and ratios there given, is seen at once.

*Ex.*—Taking the same data as last, opposite to '8 tons' in Table IV., and under '$\frac{1}{6}$,' is 2986·6 lbs. as the tractive adhesion in lbs.

Various experimenters have given the results of their labours on the tractive power of a man, which have been arranged by Professor Wallace as under, from Euler's formula:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Velocities | 0, | 1, | 2, | 3, | 4, | 5, | 6 miles per hour. |
| Power | 72, | 50, | 32, | 18, | 8, | 2, | 0 lbs. |

| | | |
|---|---|---|
| Mean absolute power of a man | in lifting, | 286 ℔s. |
| ,, ,, ,, | in drawing, | 110 ℔s. |
| ,, average ,, | ,, | 30 ℔s. |

The power of a man may be therefore taken as about one-fifth that of a horse.

The power of a horse being the dynamic used for calculating the power of steam engines by, has been variously estimated by different experimenters.

*By Tredgold's Formula.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Velocities | 2, | 3, | 3½, | 4, | 4½, | 5, | 5⅛. |
| Power | 166, | 125, | 104, | 83, | 62½, | 41⅔, | 36½. |

*By Euler's Formula.*

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Velocities | 0, | 1, | 2, | 3, | 4, | 5, | 6, | 7, | 8, | 9, | 10, | 11, | 12. |
| Power | 144, | 120, | 100, | 81, | 64, | 49, | 36, | 25, | 16, | 9, | 4, | 1, | 0. |

| | |
|---|---|
| The mean absolute power of a horse, in drawing, is about | 770 ℔s. |
| ,, average ,, ,, ,, | 150 ℔s. |

or that of five men.

The continued practical traction of the horse on canals is given as about 80 to 82 ℔s. only, and Mr. Tredgold estimates it at 83⅓ ℔s. in his Table of the maximum performances of a horse on canals, railways, and turnpike roads.

Watt's estimate is, however, that generally adopted for comparing with the powers of steam engines, and is thus obtained. He found by experiment, that a horse would raise 150 ℔s. over a pulley, travelling at a speed of 2½ miles an hour, from which his estimate of 33,000 ℔s. as the power of a horse is formed in this manner.

150 ℔s. × 13200 (the feet travelled in one hour), divided by 60 (the minutes in one hour), = 33,000 ℔s. raised 1 foot in 1 minute. By this data Watt calculated the nominal horse-power of his engines. These estimates of power will, at the end of this Paper, be compared with the engine-power on railways.

Table V.—In this Table the rise in feet per mile, and the effects of gravity for that particular inclination, are given, from a rise of 1 in 100 to a rise of 1 in 21; but by reversing the columns, the inclines are also given, from 1 in 251·43 to 1 in 52·8. For 1 in 251·43 is exactly a rise of 21 feet per mile; and 1 in 52·8 gives a rise of 100 feet per mile; and so on for any number in the Table. It is also applicable to gradients not contained therein, by applying any required multiple, as 2, 3, 4, &c., or any required divisor, as ½, ⅓, ¼, ⅙, &c., to gradients contained in the Table. For instance, the rise due to 1 in 1320 may be found by dividing 24, that due to 220, by 6 = 4 feet per mile. The gravity due to 1 in 1320 will be found by dividing that due to 33 by 40, because 40 × 33 = 1320, and $\frac{67{\cdot}88}{40} = 1{\cdot}697$, the gravity per ton due to 1 in 1320. The gravity given in the Table is in addition to the friction on a level, and is obtained by dividing the ℔s. in a ton by the ratio of the rise in feet.

For an incline, the effects of gravity must be added to the resistance on a level, and the tractive power divided by that sum, which will give the load an engine will take up the gradient given.

*Ex.*—Take, as before, an engine with a tractive power of 4976·6 ℔s. on an incline of 1 in 100,—required the load which the engine will take up this incline?

In the Table we find that a resistance of 22·4 ℔s. is due to a gradient of 1 in 100: hence 22·4 + the resistance due to the speed* (say 20 ℔s.) = 42·4 ℔s. as the resistance per ton, and $\frac{4976{\cdot}6}{42{\cdot}4} = 117{\cdot}3$ tons as the load which the engine would take up the incline of 1 in 100.

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* The resistance to trains at different velocities will be fully examined at the close of this Paper.

TABLES VI. and VIII.—To find the consumption of steam, water, and coke, multiply the area of the piston by the length of the stroke during which steam is admitted to the cylinder, and that product by the number of times the cylinder must be filled for the particular size of wheel, which will give the consumption per mile when the steam is of equal temperature and pressure during the given time.

*Ex.*—Taking an engine with 6-feet wheels, at 60 miles an hour, $15\frac{3}{4}$ cylinders, steam at 98 lbs. gross pressure, cut off at 15 inches stroke,—required the consumption of steam per mile, and for 60 miles?

By Table III. the area of $15\frac{3}{4}$ inches is 194·828 inches.

By Table VI. the number of cylinders of steam in a mile, for both cylinders and a 6-feet wheel, is 1122: hence $\frac{194{\cdot}828 \times 15 \text{ (stroke)} \times 1122}{1728} = 1897{\cdot}5$ cubic feet of steam per mile; and $1897{\cdot}5 \times 60 = 113{,}850$ cubic feet of steam required for a trip of 60 miles.

*For Water.*—Taking the steam as generated under a gross pressure of 98 lbs., by Table VIII. we find that steam at this pressure is 301 times the bulk of the water which produced it: therefore, by dividing the cubic feet of steam consumed by 301, gives the cubic feet of water required to generate that quantity of steam. As each cubic foot of water is very nearly $6\frac{1}{4}$ gallons, by multiplying the cubic feet of water found by $6\frac{1}{4}$ we have the number of gallons of water; and the gallons, multiplied by 10 lbs. (the weight of a gallon of water), give the lbs. of water also.

*Ex.*—Taking the last data,—required to know the cubic feet, gallons, and lbs. of water consumed?

We have then $\frac{113850}{301} = 378{\cdot}23$ cubic feet of water; and $378{\cdot}23 \times 6{\cdot}25 = 2364$ gallons nearly: again, $2364 \times 10 = 23640$ lbs. of water.

*For Coke.*—The usual proportion of coke to water for ordinary traffic is about 1 lb. of coke to 8 lbs. of water, or $1\frac{1}{4}$ lb. of coke per gallon of water: hence, by dividing the lbs. of water by 8, or multiplying the gallons of water by $1\frac{1}{4}$, will in each case give the quantity of coke required.

*Ex.*—Taking the data of the last, we have 2364 gallons $\times 1\frac{1}{4} = 2955$ lbs. of coke; and $\frac{23640}{8} = 2955$ lbs. also; which, being the consumption for 60 miles, gives $49\frac{1}{4}$ lbs. per mile.

These calculations are based on the supposition that steam of uniform pressure is used throughout the whole 60 miles; but as in practice this is seldom or never the case, any deviation from the uniformity of pressure will alter the quantity of coke and water consumed. However, by taking the mean or average pressure during the trip, including the atmospheric pressure of 14·75 lbs. per square inch also, and for the gross pressure taking from Table VIII. the corresponding bulk of steam to water, the quantities will be found in the same way as in the examples which have been given.

TABLE No. VII.—To find the velocity of the piston in feet per minute. Divide the distance in inches run per hour by the circumference of the driving wheel in inches, multiplied by 60 for the revolutions per minute: then multiply the revolutions per minute by double the length of the stroke of the piston in inches, and divide by 12 for the velocity of the piston in feet per minute.

*Ex.*—Let an engine have 7-feet wheels, 20 inches stroke, and velocity 50 miles an hour,—required the velocity of the piston in feet per minute?

$$\frac{50 \text{ miles} = 3168000 \text{ inches run per hour}}{7 \text{ feet} = 263{\cdot}8944 \text{ inches circumference} \times 60 \text{ minutes}} = 200 \text{ revolutions:}$$

hence $\frac{200 \times 40 \text{ inches (double stroke)}}{12} = 666{\cdot}66$ feet per minute as the velocity of the piston.

The Table shortens this operation for all velocities and sizes of wheels contained in it.

Taking the above data, in a line with '50 miles an hour,' and under '7 feet,' is 200 revolutions per minute; and as before, $\frac{200 \times 40}{12} = 666{\cdot}66$ feet per minute.

### *No. I.—Form of Express Train Time Ticket.*

______________________________ RAILWAY.

*Express Train,* ________-*day, the* ___ *of* ______ , 184 .

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ______ to ______ | | | | | | | |
| Engine ______<br>Engine-man ______<br>Fire-man ______ | Correct Time of Starting. | | Actual Time of Starting. | | Carriages. | Vans. | Correct Time of Arrival. | | Actual Time of Arrival. | | Time Lost. | REMARKS. |
| | H. | M. | H. | M. | | | H. | M. | H. | M. | | |
| | | | | | | | | | | | | |
| | A. ______ | | | | | to | | | | ______ B. | | |
| | | | | | | | | | | | | *Signed* ______ |
| | B. ______ | | | | | to | | | | ______ C. | | |
| Engine ______<br>Engine-man ______<br>Fire-man ______ | | | | | | | | | | | | |
| | C. ______ | | | | | to | | | | ______ D. | | |
| | | | | | | | | | | | | *Signed* ______ |
| | D. ______ | | | | | to | | | | ______ E. | | |
| Engine ______<br>Engine-man ______<br>Fire-man ______ | | | | | | | | | | | | |
| | E. ______ | | | | | to | | | | ______ F. | | |
| | | | | | | | | | | | | *Signed* ______ |

### *No. II.—Form of ordinary Long Train Time Ticket.*

______________________________ RAILWAY.

___ *o'Clock Train,* A. M. P. M. ________ *day, the* ___ *of* ______ 184 .

| STATIONS. | Actual Time of Starting. | | After Time. | No. of Carriages. | No. of Carriage Trucks. | No. of Horse-Boxes. | No. of Goods Waggons. | No. of Parcel Vans. | Time of Arrival. | | After Time. | Total Carriages. | No. of Miles between Stations. | Carriages conveyed one mile. | REMARKS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H. | M. | M. | | | | | | H. | M. | M. | | | | |
| A. to B. .. | | | | | | | | | | | | | | | |
| B. to C. .. | | | | | | | | | | | | | | | |
| C. to D. .. | | | | | | | | | | | | | | | |
| Engine ______ | | | | | | | | | | | | | | | |
| Engine-man ______ | | | | | | | | | | | | | | | *Signed* ______ |
| D. to E. .. | | | | | | | | | | | | | | | |
| E. to F. .. | | | | | | | | | | | | | | | |
| Engine ______ | | | | | | | | | | | | | | | |
| Engine-man ______ | | | | | | | | | | | | | | | *Signed* ______ |
| F. to G. .. | | | | | | | | | | | | | | | |
| G. to H. .. | | | | | | | | | | | | | | | |
| Engine ______ | | | | | | | | | | | | | | | |
| Engine-man ______ | | | | | | | | | | | | | | | *Signed* ______ |

### *No. III.—Form of Time, Coke, and Mileage Ticket, where there is no Change of Engine.*

____________________ BRANCH TICKET.

________________RAILWAY. ______*day, the* ___ *day of*__________, 184 .

Engine ______

Engine-man ______

Fire-man ______

| | No. of Trips. | No. of Miles. | No. of Carriages. |
|---|---|---|---|
| With Passenger Trains | | | |
| ,, Goods ,, | | | |
| Assisting............ | | | |
| Empty ........... | | | |
| Total Miles .... | | | |

| | TIME IN DAYS. | |
|---|---|---|
| | Engine-man. | Fire-man. |
| Running.............. | | |
| Piloting.............. | | |
| Shed time on Repairs.... | | |
| Total...... | | |

| STATIONS. | Coke. cwts. | Small Coke. cwts. | Coal. cwts. | Oil. pints. | Tallow. lbs. | Signature of Coke-man. |
|---|---|---|---|---|---|---|
| | | | | | | |
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| | | | | | | |

TABLE OF UP TRAINS FROM __________.

| Correct Time of Starting. | | Time on Journey. | | Late in Starting. | Late in Arriving. | Description of Load. | | | | | REMARKS. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| H. | M. | H. | M. | M. | M. | Carriages. | Trucks. | Horse-Boxes. | Goods Waggons. | Parcel Vans. | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

TABLE OF DOWN TRAINS FROM __________.

| Correct Time of Starting. | | Time on Journey. | | Late in Starting. | | Late in Arriving. | | Description of Load. | | | | | REMARKS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H. | M. | H. | M. | H. | M. | M. | M. | Carriages. | Trucks. | Horse-Boxes. | Goods Waggons | Parcel Vans. | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

*Engine-man's Signature* ____________________

### *No. IV.—Form for Short or Special Trips.*

______________________________RAILWAY.

*Particulars of Trips for* _____*day, the* _____ *of* ________, 184 . __________*Station.*

| Name of Engine. | Name of Engine-man. | Where from. | Where to. | Departure. | | Late in Starting. | Late in Arrival. | Time on Journey. | | Description of Load. | | | | | REMARKS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | H. | M. | M. | M. | H. | M. | Carriages. | Carriage Trucks. | Horse-Boxes. | Goods Waggons. | Parcel Vans. | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |

### *No. V.—Form of Goods, Time, and Train Ticket for Long Trains.*

*No.*________ ______________________________ RAILWAY.

*Engine* __________________ *Engine-man* ______________________________

______ *o'Clock Train,* _____ M. ________ *day, the* ______ *day of* ______________ 184 .

| STATIONS. | Arrived. | | Started. | | Taken on. | | | | | Put off. | | | | | Late at Starting, and Detention at Stations. | Total Carriages. | Miles between Stations. | Carriages conveyed one mile. | REMARKS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H. | M. | H. | M. | Carriages. | Trucks. | Horse-Boxes. | Goods Waggons. | Parcel Vans. | Carriages. | Trucks. | Horse-Boxes. | Goods Waggons. | Parcel Vans. | | | | | |
| A. ________ | | | | | | | | | | | | | | | | | | | Late on arrival. |
| B. ________ | | | | | | | | | | | | | | | | | | | Cause of being late. |
| C. ________ | | | | | | | | | | | | | | | | | | | |
| D. ________ | | | | | | | | | | | | | | | | | | | |
| E. ________ | | | | | | | | | | | | | | | | | | | |
| F. ________ | | | | | | | | | | | | | | | | | | | |
| Total No. put on . | | | | | | | | | | | | | | | | | | | |
| Do. put off . . | | | | | | | | | | | | | | | | | | | |
| Do. arrived with | | | | | | | | | | | | | | | | | | | |

*Signature of Engine-man* ____________________

*Engine* ____________________ *Engine-man* ____________________

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F. ________ | | | | | | | | | | | | | | | | | | | Late on arrival. |
| G. ________ | | | | | | | | | | | | | | | | | | | Cause of being late. |
| H. ________ | | | | | | | | | | | | | | | | | | | |
| I. ________ | | | | | | | | | | | | | | | | | | | |
| K. ________ | | | | | | | | | | | | | | | | | | | |
| Total No. put on . | | | | | | | | | | | | | | | | | | | |
| Do. put off . . | | | | | | | | | | | | | | | | | | | |
| Do. arrived with | | | | | | | | | | | | | | | | | | | |

*Signature of Engine-man* ____________________

### *No. VI.—Form of Coke and Mileage Ticket.*

*No.*____ ______________ RAILWAY. ____________ *Station,*_____ *day of*__________, 184 .

Engine ____________________

Engine-man ____________________

Fire-man ____________________

*Total number of Miles and Trips run during the Day.*

| | No. of Trips. | No. of Miles. | No. of Car'ges. |
|---|---|---|---|
| With Passenger Trains | | | |
| ,, Goods Trains . | | | |
| Assisting . . . . | | | |
| Empty . . . . . | | | |
| Total . | | | |
| Piloting ______ hours. | | | |
| Banking ______ do. | | | |

| Coke put in Tender at | Coke. cwts. | Small Coke. cwts. | Coal. cwts. | Oil. pints. | Tallow. ℔s. | Signature of Coke-man. |
|---|---|---|---|---|---|---|
| A. ________ | | | | | | |
| B. ________ | | | | | | |
| C. ________ | | | | | | |
| D. ________ | | | | | | |
| E. ________ | | | | | | |
| F. ________ | | | | | | |
| Total . | | | | | | |

*Engine-man's Signature* ______________________________

*Form on Back of Coke and Mileage Ticket.—Distances from Station to Station.*

Miles.

A. ____________ to B. ____________
„ ____________ to C. ____________
„ ____________ to D. ____________
D. ____________ to E. ____________
„ ____________ to F. ____________
F. ____________ to G. ____________
„ ____________ to H. ____________
H. ____________ to I. ____________
„ ____________ to K. ____________

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## No. VII.—*Abstract of Best Coke, Small Coke, Coal, and Oil, consumed by Locomotive Engines, and Miles run During the Week, ending ________ day, the ______ day of ________ 184 .*

________________________ RAILWAY.

| Name of Engine. | Name of Engine-man. | Miles. | | | No. of Hours piloted. | Best Coke in cwts. | Small Coke in cwts. | Coal in cwts. | Coke and Coal in lbs. per mile. | Oil and Tallow in lbs. | Average of Oil and Tallow in lbs. per mile. | Average No. of Carriages per Trip. | Trips in which Time has been | | | | | Premiums to Engine-men and Fire-men. | REMARKS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Kept. | Made up. | | Lost. | | | |
| | | With Trains. | Empty. | Total. | | | | | | | | | No. | No. | Minutes made up. | No. | Minutes lost. | | |
| | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | |
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| | | | | | | | | | | | | | | | | | | | |

### ABSTRACT OF TOTALS FOR EACH STATION.

| Name of Station. | Total Miles. | Total Best Coke in cwts. | Total Small Coke in cwts. | Total Coal in cwts. | Average of Coke and Coal per mile in lbs. | Total Oil and Tallow in lbs. | Average of Oil per mile in lbs. | Empty miles included in Total miles. | Average No. of Carriages per Trip. |
|---|---|---|---|---|---|---|---|---|---|
| A. ________ | | | | | | | | | |
| B. ________ | | | | | | | | | |
| C. ________ | | | | | | | | | |
| D. ________ | | | | | | | | | |
| E. ________ | | | | | | | | | |
| Goods and Banking .. | | | | | | | | | |
| Third Class ........ | | | | | | | | | |
| On Trial............ | | | | | | | | | |
| Totals ........ | | | | | | | | | |

### FINES.

| Name. | Cause of Fine. | Amount. |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

## EXPLANATION OF TICKETS.

No. I. is for express trains, where the proper time of arrival is printed on the ticket, opposite to each stopping station; the engine-man filling in the actual time of his arrival at each station. When he comes to a station where a change of engines takes place, he must fill up his part of the ticket, with remarks (if any), sign it, and hand it to the engine-man who takes on the train, who must also do so in like manner at another change of engines, and so on to the end of the journey, when the last engine-man is responsible that the ticket is given in to the proper person appointed to receive and register its contents.

No. II. is a form for ordinary passenger trains, with the names of the stations where a change of carriages, &c., takes place printed in the margin, and columns for the time, number, and description of vehicles at each station, with mileage columns, which show the exact number of miles run by the carriages of the train. It is filled up precisely as No. I. by each engine-man, and given in to the proper office by the last engine-man, as before.

No. III. is a form embracing time, coke, and mileage in one ticket, and is adapted for all short lines or branches where the same engine runs the entire length of the line or branch, and returns again with the next following train; and will do for one, two, or more such return trips on the same day.

No. IV. is a form for short trips, filled up as indicated by the columns for each trip made by the same engine on the same day.

No. V. is a form for goods and third-class trains, with the names of each station along the margin, and extra columns showing the number of vehicles taken on or put off during the journey, all which must be duly filled up by the engine-man in the same way as No. I., and handed to the engine-man who takes on the train, who in like manner must do the same for his part of the journey, and give in the ticket at the end of the trip, as before.

No. VI. is a form for a coke and mileage ticket, which accompanies the same engine for one day, and is not parted with by the engine-man until his day's work is completed, when he must fill it up, and give it in to the proper person authorized to receive it. On the back of this ticket it is usual to print the distances from station to station, that the engine-man may accurately fill in the mileage of his engine by them.

The names of coking and watering stations only are printed in the margin of this ticket, leaving two lines to each station for the entry of coke for either an outward or inward journey.

When these tickets have been filled up and given in by the engine-man, the total mileage and mean load is thus obtained: multiply the number of carriages travelling between each stopping station by the distance between those stations, and at the end of the journey add these products together for the total mileage; divide this by the whole distance travelled by the engine, which will give the mean load.

*Ex.*—Suppose a train of twelve carriages starts from A. to run to C. without stopping, the distance being 10 miles; and from C. to D., 20 miles, with ten carriages; also from D. to E., 15 miles, with fifteen carriages,—required the total mileage and mean load?

From A. to C. 10 miles × 12 carriages = 120
C. to D. 20 „ × 10 „ = 200
D. to E. 15 „ × 15 „ = 225
Total distance 45 „ Total mileage 545

And $\frac{545}{45}$ = 12·1 carriages as the mean load over the 45 miles.

These tickets, when properly filled up, and the information they contain duly recorded, supply very accurate details, both of the mileage and of the comparative economy of the engines and engine-men, and bring into play a wholesome spirit of economical rivalry and careful conduct on their part.

No. VII. is a form for the weekly abstract of the work done, and consumption of fuel and stores for that work, for each engine. It is made up from the data on the preceding Tickets, and one placed at each engine station, that the engine-men and fire-men may see their own consumption and work contrasted with that of others. The premiums are determined by the saving made over a standard fixed by the superintendent for the particular part of the line, and the particular duty the engines have to perform.

The letters A. B. C. D. and E. in the abstract of totals for each station represent the names of the engine stations, so that at any one station the engine-men and fire-men see the comparative average consumption of the other stations.

The headings of the columns are so full that they clearly indicate how the form should be filled up without further explanation.

The prospect of reward, in the shape of premiums for good conduct at the end of the year, operates as a stimulus to constant watchfulness that such may not be forfeited by neglect; and whilst it encourages the engine-man, it also more than remunerates his employers for the boon they hold out to him.

## TABLES OF RESISTANCES TO RAILWAY TRAINS.

### TABLE IX.

*Table of the Results of various Experiments, showing the Resistance to Trains of different Weights and at different Velocities, in all cases where such velocities have been uniformly maintained in calm weather, on Lines of uniform inclination, and free from sharp curves; the road and carriages being in good working order. The resistances are measured either by the effect of gravity on inclined planes, or by the difference of pressure on the travelling piston of the Atmospheric Railway apparatus, except in two cases marked with a †, in which the resistance is indicated approximately by the effect theoretically due to steam generated and made use of under known conditions in a Locomotive Engine.*

| No. of carriages. | Uniform velocity maintained in miles per hour. | Weight. | Resistance in lbs. per ton. | Resistance in lbs. per ton, as Formula. | Wind. | No. of carriages. | Uniform velocity maintained in miles per hour. | Weight. | Resistance in lbs. per ton. | Resistance in lbs. per ton, as Formula. | Wind. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Miles. | Tons. | lbs. | lbs. | | No. | Miles. | Tons. | lbs. | lbs. | |
| 2 | 14 | 9· | 12·6 | 13·9 | Fav$^{\text{ble}}$. | 6 | 34 | 30·4 | 25·0 | 23·1 | Nearly calm. |
| 2 | 14 | 9· | 12·6 | 13·9 | ,, | 4 | 34 | 18·05 | 23·4 | 27·2 | Favourable. |
| 4 | 16 | 20·5 | 8·5 | 13·2 | ,, | 6 | 35 | 21·5 | 22·5 | 26·1 | Calm. |
| 8 | 19 | 40·75 | 8·5 | 12·9 | ,, | E. T. & 9 | 36 | 64· | 22·5 | 22·4 | ,, |
| 8 | 20 | 40·75 | 8·5 | 14·1 | ,, | 4 | 37 | 20·4 | 25·0 | 28·4 | Favourable. |
| 4 | 21 | 18· | 12·6 | 16·7 | ,, | 3 | 39 | 24·0 | 30·0 | 31·0 | ,, B. |
| 4 | 21 | 18· | 12·6 | 16·7 | ,, | E.T.&13 | 45 | 111· | 30·3 | 24·9 | Nearly calm.† |
| 4 | 23 | 20·5 | 12·6 | 17·5 | ,, | E. T. & 3 | 46 | 54· | 30· | 27·5 | Light, fav. B. |
| 8 | 25 | 40·75 | 12·6 | 16·6 | ,, | 3 | 47 | 31·75 | 33·7 | 33·1 | Light, against. |
| 8 | 26 | 40·75 | 12·6 | 17·1* | ,, | 6 | 50 | 30· | 32·9 | 35·3 | Calm. |
| 8 | 27 | 40·75 | 12·6 | 17·7 | ,, | 5 | 53 | 25· | 41·7 | 42·1 | ,, |
| 4 | 31 | 15·6 | 23·4 | 25·4 | ,, | 5 | 55 | 26· | 36· | 43·5 | Light, against. |
| 4 | 32 | 14·5 | 22·5 | 27·2 | Calm. | E. T. & 6 | 55 | 93· | 41·3 | 31·6 | Calm.† B. |
| E. T. & 6 | 33 | 44· | 22·5 | 22·7 | ,, | 4 | 61 | 21·5 | 52·6 | 54·8 | ,, |

*Note.*—E. T. signifies that these experiments were made with an engine and tender in front. All the others were made with carriages only.

* Space between carriages made up with stretched canvass.

B. Experiments on broad gauge.

## TABLE X.

*Table to facilitate the Calculation of the Resistances to Passenger Trains on a calm day, on a level line, practically straight, the Rails and Carriages being in good working order, and generally in the absence of any disturbing cause calculated to affect materially the amount of resistance: calculated from Formula.*

| Velocity in miles per hour. | Resistance from friction. | Resistance varying as velocity. | Sum of the two resistances. | Resistance of the atmosphere per square foot of frontage of train. | Velocity in miles per hour. | Resistance from friction. | Resistance varying as velocity. | Sum of the two resistances. | Resistance of the atmosphere per square foot of frontage of train. |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 6 | 3·3 | 9·3 | 0·25 | 44 | 6 | 14·6 | 20·6 | 4·84 |
| 12 | 6 | 4· | 10· | 0·36 | 45 | 6 | 15· | 21· | 5·06 |
| 14 | 6 | 4·6 | 10·6 | 0·49 | 46 | 6 | 15·3 | 21·3 | 5·29 |
| 16 | 6 | 5·3 | 11·3 | 0·64 | 47 | 6 | 15·6 | 21·6 | 5·52 |
| 18 | 6 | 6· | 12· | 0·81 | 48 | 6 | 16· | 22· | 5·76 |
| 20 | 6 | 6·6 | 12·6 | 1· | 49 | 6 | 16·3 | 22·3 | 6· |
| 22 | 6 | 7·3 | 13·3 | 1·21 | 50 | 6 | 16·6 | 22·6 | 6·25 |
| 24 | 6 | 8· | 14· | 1·44 | 51 | 6 | 17· | 23· | 6·50 |
| 26 | 6 | 8·6 | 14·6 | 1·69 | 52 | 6 | 17·3 | 23·3 | 6·76 |
| 28 | 6 | 9·3 | 15·3 | 1·96 | 53 | 6 | 17·6 | 23·6 | 7·02 |
| 30 | 6 | 10· | 16· | 2·25 | 54 | 6 | 18· | 24· | 7·29 |
| 32 | 6 | 10·6 | 16·6 | 2·56 | 55 | 6 | 18·3 | 24·3 | 7·56 |
| 34 | 6 | 11·3 | 17·3 | 2·89 | 56 | 6 | 18·6 | 24·6 | 7·84 |
| 36 | 6 | 12· | 18· | 3·24 | 57 | 6 | 19· | 25· | 8·12 |
| 38 | 6 | 12·6 | 18·6 | 3·61 | 58 | 6 | 19·3 | 25·3 | 8·41 |
| 40 | 6 | 13·3 | 19·3 | 4· | 59 | 6 | 19·6 | 25·6 | 8·70 |
| 41 | 6 | 13·6 | 19·6 | 4·22 | 60 | 6 | 20· | 26· | 9· |
| 42 | 6 | 14· | 20· | 4·41 | 61 | 6 | 20·3 | 26·3 | 9·30 |
| 43 | 6 | 14·3 | 20·3 | 4·62 | | | | | |

"*Note.*—The correction for gravity on any given inclination is of course easily applied to the results of the formula. In cases of accelerating and retarding velocities a correction will be requisite, on account of part of the train being in rotatory motion. (See Report of Mr. E. Wood, page 248 of 'Report of British Association,' 1841.) It is scarcely necessary to caution Engineers, that in applying the results of such a Table as the above for practical purposes, care must be taken that the circumstances assumed, and necessarily so, in the formula suggested, coincide with the actual circumstances of the case to which it is sought to apply the formula."

For miles not in this Table, take the mean resistances between the two nearest mileages for the resistance due to the even miles per hour. Thus for a train of 18 tons at 21 miles an hour, and frontage 60 feet, take for 20 miles $\frac{12·6 + 13·3}{2}$ for 22 miles $= 12·95$ lbs. at 21 miles $\times$ 18 tons $= 233·1$ lbs. for friction and concussion resistance. For atmospheric resistance we have $\frac{1 + 1·21}{2} = 1·105 \times 60$ ft. $= 66·3$ lbs.; and $\frac{233·1 + 66·3}{18} = 16·63$ lbs. per ton.

For tenth parts of a mile, multiply the number of tenth parts of a mile by one-tenth the difference between the mean resistance found as above, and the next mileage, or by one-tenth the difference between the nearest mileages when they are given consecutively.

Taking the velocity 21·4 miles per hour and train 18 tons, as before, we have for the train 22 miles $\frac{13·3 - 12·95}{10}$ for 21 miles $\times 4 + 12·95 = 13·09$ lbs. $\times$ 18 tons $= 235·62$ lbs., and for the atmosphere $\frac{1·21 - 1·105}{10} \times 4 + 1·105 = 1·147 \times 60 = 68·82$ lbs.; and $\frac{235·62 + 68·82}{18} = 16·9$ lbs. per ton.

# TABLE XI.

*Table of the Indicator and Dynamometer Resistances to Railway Trains on the Broad Gauge, abstracted from the Experiments of Mr. D. Gooch, as published in the Appendix to the Railway Commissioners' Report to the House of Lords, showing the Resistances, separately, of the Engine, Train, and Working Parts of the Engine; also the separate Resistances as calculated by the Formula explained in this Paper.*

| 1st Series of Experiments, made with a Train of 100 Tons, exclusive of Engine and Tender. | | | | | | | | | | | | | | Theoretical Resistances for 100 Tons Trains. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Resistance in lbs. | | | | | Velocity | Weight. | | | Resistance in lbs. per ton | | | Velocity. | Remarks. | Resistances by Formula in lbs. | | | | | | In lbs. per ton. | | |
| | | | | | | | | | | | | | | of Train only. | | | | | | | | |
| Of train only by Dynamometer. | Of engine and train by Indicator. | Of engine and tender only. | Of engine and tender at the ratio of the train. | Of working parts of the engine. | In miles per hour. | Of engine and tender. | Of train. | Total. | Of train only by Dynamometer. | Of engine and train by Indicator. | Of engine and tender. | Variations of. (I.) Increased. (R.) Reduced. | State of the weather, &c. | Friction. | Atmospheric. | Oscillation. | Total of train. | Of engine and tender. | Total of engine and train. | Of train only. | Of engine and tender. | Of engine and train. |
| lbs. | lbs. | lbs. | lbs. | lbs. | Miles. | Tons. | Tons. | Tons. | lbs. | lbs. | lbs. | Miles. | | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. |
| 756 | 1363 | 607 | 383·3 | 223·7 | 13·1 | 50·7 | 100 | 150·7 | 7·56 | 9·04 | 11·97 | R. 1·4 | slight side. | 600 | 61·7 | 87·3 | 749 | 620· | 1369 | 7·49 | 12·23 | 9·08 |
| 843 | 1794 | 951 | 435· | 516· | 19·4 | 51·6 | 100 | 151·6 | 8·43 | 11·83 | 18·43 | I. 1·6 | slight. | 600 | 135·4 | 128· | 863 | 836· | 1699 | 8·63 | 16·2 | 11·2 |
| 901 | 1623 | 722 | 457·7 | 264·3 | 19·8 | 50·8 | 100 | 150·8 | 9·01 | 10·76 | 14·21 | I. 1·1 | moderate side. | 600 | 141·1 | 132· | 873 | 836· | 1709 | 8·73 | 16·45 | 11·33 |
| 909 | 1736 | 827 | 445·4 | 381·6 | 19·8 | 49· | 100 | 149· | 9·09 | 11·65 | 16·88 | uniform. | strong side. | 600 | 141·1 | 132· | 873 | 806·5 | 1679 | 8·73 | 16·5 | 11·26 |
| 819 | 1845 | 1026 | 411·1 | 614·9 | 20·2 | 50·2 | 100 | 150·2 | 8·19 | 12·28 | 20·43 | I. 1·7 | moderate side. | 600 | 146·8 | 134·6 | 881 | 839·8 | 1721 | 8·81 | 16·73 | 11·46 |
| 843 | 1650 | 807 | 428·2 | 378·8 | 21·1 | 50·8 | 100 | 150·8 | 8·43 | 10·94 | 15·88 | uniform. | do. do. | 600 | 160·2 | 140·6 | 900 | 880· | 1780 | 9· | 17·32 | 11·8 |
| 2110 | 3891 | 1781 | 1101·4 | 679·6 | 44·1 | 52·2 | 100 | 152·2 | 21·1 | 25·56 | 34·11 | I. 3·5 | strong side. | 600 | 700· | 294· | 1594 | 1817· | 3411 | 15·94 | 34·8 | 22·41 |
| 1436 | 3237 | 1801 | 692·1 | 1108·9 | 45·3 | 48·2 | 100 | 148·2 | 14·36 | 21·84 | 37·36 | I. 1·8 | do. do. | 600 | 738·7 | 302· | 1640 | 1728·3 | 3368 | 16·4 | 35·85 | 22·72 |
| 1850 | 3761 | 1911 | 925· | 986· | 45·6 | 50· | 100 | 150· | 18·50 | 25·07 | 38·22 | uniform. | slight side. | 600 | 748·5 | 304· | 1652 | 1805·8 | 3458 | 16·52 | 36·11 | 23·05 |
| 2180 | 4649 | 2469 | 1072·5 | 1396·5 | 56·6 | 49·2 | 100 | 149·2 | 21·8 | 31·16 | 50·18 | ,, | strong side. | 600 | 1153· | 377·3 | 2130 | 2268·8 | 4399 | 21·3 | 46·11 | 29·48 |
| 1781 | 3556 | 1775 | 872·6 | 902·4 | 57·4 | 49· | 100 | 149· | 17·81 | 23·86 | 36·22 | R. 1·4 | do. do. | 600 | 1186· | 382·6 | 2168 | 2296·8 | 4465 | 21·68 | 46·85 | 29·96 |
| 2183 | failed. | | | | 58·1 | 50·2 | 100 | 150·2 | 21·83 | failed. | | I. 1·6 | do. do. | 600 | 1215· | 387·3 | 2202 | 2387· | 4589 | 22·02 | 47·55 | 30·55 |
| 2438 | ,, | | | | 59·4 | 45·8 | 100 | 145·8 | 24·38 | ,, | | I. 1·6 | do. do. | 600 | 1270· | 396· | 2264 | 2238· | 4502 | 22·64 | 48·87 | 30·88 |
| 1980 | ,, | | | | 61·3 | 49·5 | 100 | 149·5 | 19·8 | ,, | | uniform. | nearly calm. | 600 | 1352· | 408·6 | 2360 | 2508·5 | 4869 | 23·60 | 50·68 | 32·56 |
| 2nd Series of Experiments, made with a Train of 50 Tons, exclusive of Engine and Tender. | | | | | | | | | | | | | | Theoretical Resistances for 50 Tons Trains. | | | | | | | | |
| 443 | 1404 | 961 | 454·5 | 506·5 | 19·8 | 51·3 | 50 | 101·3 | 8·86 | 13·87 | 18·73 | I. 1·1 | slight side. | 300 | 70·5 | 66· | 436 | 804·5 | 1240 | 8·72 | 15·68 | 12·24 |
| 464 | 1437 | 973 | 450· | 523· | 21·8 | 48·5 | 50 | 98·5 | 9·28 | 14·58 | 20·06 | partly unif$^{m}$. | moderate. | 300 | 85·5 | 72·6 | 458 | 817·2 | 1275 | 9·16 | 16·85 | 12·94 |
| 521 | 1417 | 896 | 521· | 375· | 24·7 | 50· | 50 | 100· | 10·42 | 14·17 | 17·92 | I. 1·3 | strong side. | 300 | 109·8 | 82·3 | 492 | 928·5 | 1420 | 9·84 | 18·57 | 14·20 |
| 1194 | 3162 | 1968 | 1234·5 | 733·5 | 40·1 | 51·7 | 50 | 101·7 | 23·88 | 31·09 | 38·06 | I. 7·8 | slipping. | 300 | 289·4 | 133·6 | 723 | 1461·6 | 2184 | 14·46 | 28·27 | 21·48 |
| 690 | 1923 | 1233 | 684·5 | 548·5 | 42·3 | 49·6 | 50 | 99·6 | 13·8 | 19·3 | 24·86 | uniform. | slight side. | 300 | 322· | 141· | 763 | 1474·7 | 2237 | 15·26 | 29·73 | 22·46 |
| 724 | 2085 | 1361 | 716·7 | 644·3 | 43·9 | 49·5 | 50 | 99·5 | 14·48 | 20·95 | 27·49 | ,, | strong side. | 300 | 346·8 | 146·3 | 793 | 1524·7 | 2317 | 15·86 | 30·8 | 23·29 |
| 786 | 1961 | 1175 | 798·5 | 376·5 | 44· | 50·8 | 50 | 100·8 | 15·72 | 19·45 | 23·11 | R. 3· | stormy, slipping. | 300 | 348·4 | 146·6 | 795 | 1568·2 | 2363 | 15·9 | 30·87 | 23·44 |
| 854 | 2711 | 1857 | 855·7 | 1001·3 | 51·2 | 50·1 | 50 | 100·1 | 17·08 | 27·08 | 37·07 | R. 4· | stormy ahead. | 300 | 471· | 170·6 | 942 | 1795·5 | 2737 | 18·82 | 35·84 | 27·33 |
| 1111 | 3196 | 2085 | 1126·5 | 958·5 | 58· | 50·7 | 50 | 100·7 | 22·22 | 31·73 | 41·12 | I. 1·4 | slipping. | 300 | 605·5 | 193·3 | 1098 | 2064·7 | 3162 | 21·96 | 40·72 | 31·4 |
| 1309 | 3278 | 1969 | 1314·2 | 654·8 | 59·2 | 50·2 | 50 | 100·2 | 26·18 | 32·71 | 39·22 | I. 3·2 | moderate side. | 300 | 630·8 | 197·4 | 1128 | 2088· | 3216 | 22·56 | 41·6 | 32·09 |
| 1539 | 3731 | 2192 | 1520·5 | 671·5 | 59·2 | 49·4 | 50 | 99·4 | 30·78 | 37·53 | 44·37 | I. 3·2 | strong side. | 300 | 630·8 | 197·4 | 1128 | 2055· | 3183 | 22·56 | 41·6 | 32·02 |
| 819 | 2374 | 1555 | 825·5 | 729·5 | 62·4 | 50·4 | 50 | 100·4 | 16·38 | 23·64 | 30·85 | R. 7· | calm. | 300 | 700·8 | 208· | 1208 | 2216·6 | 3414 | 24·16 | 43·98 | 34· |
| 3rd Series of Experiments, made with a Train of 80 Tons, exclusive of Engine and Tender. | | | | | | | | | | | | | | Theoretical Resistances for 80 Tons Trains. | | | | | | | | |
| 1036 | cards not taken. | | | | 43·2 | 50· | 80 | 130 | 12·95 | cards not taken. | | R. 4·6 | up grad$^{t}$. $\frac{1}{352}$. allow$^{d}$. 6·3 lbs. per ton. | 480 | 537·4 | 230·4 | 1247·8 | 1628·5 | 2876 | 15·59 | 32·57 | 22·12 |
| 836 | | | | | 47· | 50· | 80 | 130 | 10·45 | | | R. 1·9 | | 480 | 636·1 | 250·6 | 1366·7 | 1778· | 3144 | 17·08 | 35·56 | 24·17 |
| 1772 | | | | | 48·5 | 50· | 80 | 130 | 22·15 | | | I. 3·7 | calm. | 480 | 677·4 | 258·6 | 1416· | 1838· | 3254 | 17·7 | 36·76 | 25·03 |
| 632 | | | | | 51·9 | 50· | 80 | 130 | 7·9 | | | R. 5· | mom$^{m}$. given out. | 480 | 773·7 | 276·8 | 1530·5 | 1978·3 | 3509 | 19·13 | 39·56 | 26·99 |
| 1555 | | | | | 56·8 | 50· | 80 | 130 | 19·4 | | | I. 1·4 | calm. | 480 | 929·1 | 302·9 | 1712·0 | 2186· | 3898 | 21·4 | 43·72 | 29·98 |

## TABLE XII.

*Table to facilitate the Calculation of Resistances to Broad-guage Locomotive Engines of the class of the 'Great Britain' (weighing about* 50 *tons), and Trains, in ℔s. per ton, and in ℔s. per cubic foot of Bulk, on a calm day, on a level line in good order, with Engine, Tender, and Carriages, also in good working order, from* 5 *to* 75 *miles per hour: calculated from Formula, page* 53, *based on the Indicator and Dynamometer Traction of the Experiments made by Mr. D. Gooch on the Bristol and Exeter Railway.*

| Velocity. | Resistance in ℔s. per ton. | | | | | |
|---|---|---|---|---|---|---|
| | Friction and Oscillation. | Atmosphere per ton of 180 cubic feet of bulk. | Total resistance of the carriages per ton. | Engine and Tender. | | Atmosphere per cubic foot of bulk. |
| | | | | Per ton of their own weight. | Per ton of the weight of the train. | |
| Miles. | ℔s. | ℔s. | ℔s. | ℔s. | ℔s. | ℔s. |
| 5 | 6·33 | ·090 | 6·42 | 7·5 | ·001 | ·0005 |
| 6 | 6·4 | ·129 | 6·539 | 8· | ·0014 | ·00072 |
| 7 | 6·46 | ·176 | 6·636 | 8·5 | ·0019 | ·00097 |
| 8 | 6·53 | ·230 | 6·76 | 9· | ·0025 | ·00128 |
| 9 | 6·6 | ·291 | 6·891 | 9·5 | ·0032 | ·00162 |
| 10 | 6·66 | ·36 | 7·02 | 10· | ·004 | ·002 |
| 11 | 6·73 | ·435 | 7·165 | 10·5 | ·0048 | ·00242 |
| 12 | 6·8 | ·518 | 7·318 | 11· | ·0057 | ·00288 |
| 13 | 6·86 | ·608 | 7·468 | 11·5 | ·0067 | ·00338 |
| 14 | 6·93 | ·705 | 7·635 | 12· | ·0078 | ·00392 |
| 15 | 7· | ·81 | 7·81 | 12·5 | ·009 | ·0045 |
| 16 | 7·06 | ·921 | 7·981 | 13· | ·0102 | ·00512 |
| 17 | 7·13 | 1·04 | 8·13 | 13·5 | ·0115 | ·00578 |
| 18 | 7·2 | 1·166 | 8·366 | 14· | ·0129 | ·00648 |
| 19 | 7·26 | 1·299 | 8·559 | 14·5 | ·0144 | ·00722 |
| 20 | 7·33 | 1·44 | 8·77 | 15· | ·016 | ·008 |
| 21 | 7·4 | 1·587 | 8·987 | 15·5 | ·0176 | ·00882 |
| 22 | 7·46 | 1·742 | 9·202 | 16· | ·0193 | ·00968 |
| 23 | 7·53 | 1·904 | 9·454 | 16·5 | ·0211 | ·01058 |
| 24 | 7·6 | 2·073 | 9·673 | 17· | ·023 | ·01152 |
| 25 | 7·66 | 2·25 | 9·885 | 17·5 | ·025 | ·01252 |
| 26 | 7·73 | 2·43 | 10·16 | 18· | ·026 | ·01352 |
| 27 | 7·8 | 2·62 | 10·42 | 18·5 | ·0291 | ·01458 |
| 28 | 7·86 | 2·82 | 10·68 | 19· | ·0313 | ·01568 |
| 29 | 7·93 | 3·027 | 10·957 | 19·5 | ·0336 | ·01682 |
| 30 | 8· | 3·24 | 11·24 | 20· | ·036 | ·018 |
| 31 | 8·06 | 3·459 | 11·51 | 20·5 | ·0384 | ·01922 |
| 32 | 8·13 | 3·68 | 11·81 | 21· | ·0409 | ·02048 |
| 33 | 8·2 | 3·92 | 12·12 | 21·5 | ·0435 | ·02178 |
| 34 | 8·26 | 4·16 | 12·42 | 22· | ·0462 | ·02312 |
| 35 | 8·33 | 4·41 | 12·74 | 22·5 | ·049 | ·0245 |
| 36 | 8·4 | 4·66 | 13·06 | 23· | ·0518 | ·02592 |
| 37 | 8·46 | 4·92 | 13·38 | 23·5 | ·0547 | ·02738 |
| 38 | 8·53 | 5·19 | 13·72 | 24· | ·0577 | ·02888 |
| 39 | 8·6 | 5·47 | 14·07 | 24·5 | ·0608 | ·03042 |
| 40 | 8·66 | 5·76 | 14·42 | 25· | ·064 | ·0320 |
| 41 | 8·73 | 6·05 | 14·78 | 25·5 | ·0672 | ·03362 |
| 42 | 8·8 | 6·35 | 15·15 | 26· | ·0705 | ·03528 |
| 43 | 8·86 | 6·65 | 15·51 | 26·5 | ·0739 | ·03699 |
| 44 | 8·93 | 6·97 | 15·89 | 27· | ·0774 | ·03872 |
| 45 | 9· | 7·29 | 16·39 | 27·5 | ·081 | ·0405 |
| 46 | 9·06 | 7·61 | 16·67 | 28· | ·0846 | ·04232 |
| 47 | 9·13 | 7·95 | 17·08 | 28·5 | ·0883 | ·04418 |
| 48 | 9·2 | 8·29 | 17·49 | 29· | ·0921 | ·04608 |
| 49 | 9·26 | 8·64 | 17·90 | 29·5 | ·096 | ·04802 |
| 50 | 9·33 | 9· | 18·33 | 30· | ·10 | ·05 |
| 51 | 9·4 | 9·36 | 18·76 | 30·5 | ·104 | ·05202 |
| 52 | 9·46 | 9·73 | 19·19 | 31· | ·1081 | ·05408 |
| 53 | 9·53 | 10·11 | 19·64 | 31·5 | ·1123 | ·05618 |
| 54 | 9·6 | 10·49 | 20·09 | 32· | ·116 | ·05832 |
| 55 | 9·66 | 10·89 | 20·55 | 32·5 | ·121 | ·0605 |
| 56 | 9·73 | 11·29 | 21·02 | 33· | ·1254 | ·06272 |
| 57 | 9·8 | 11·69 | 21·49 | 33·5 | ·1299 | ·06498 |
| 58 | 9·86 | 12·11 | 21·97 | 34· | ·1345 | ·06728 |
| 59 | 9·93 | 12·53 | 22·46 | 34·5 | ·1392 | ·06962 |
| 60 | 10· | 12·96 | 22·96 | 35· | ·144 | ·072 |
| 61 | 10·06 | 13·39 | 23·45 | 35·5 | ·1488 | ·07442 |
| 62 | 10·13 | 13·83 | 23·96 | 36· | ·1537 | ·07688 |
| 63 | 10·2 | 14·29 | 24·49 | 36·5 | ·1587 | ·07938 |
| 64 | 10·26 | 14·74 | 25·00 | 37· | ·1638 | ·08192 |
| 65 | 10·33 | 15·21 | 25·54 | 37·5 | ·169 | ·0845 |
| 66 | 10·4 | 15·68 | 26·08 | 38· | ·1742 | ·08712 |
| 67 | 10·46 | 16·16 | 26·62 | 38·5 | ·1795 | ·08978 |
| 68 | 10·57 | 16·46 | 27·01 | 39· | ·1849 | ·09248 |
| 69 | 10·6 | 17·14 | 27·74 | 39·5 | ·1904 | ·09522 |
| 70 | 10·66 | 17·64 | 28·30 | 40· | ·196 | ·098 |
| 71 | 10·73 | 18·14 | 28·87 | 40·5 | ·2016 | ·10082 |
| 72 | 10·8 | 18·66 | 29·46 | 41· | ·2073 | ·10368 |
| 73 | 10·86 | 19·18 | 30·04 | 41·5 | ·2131 | ·10658 |
| 74 | 10·93 | 19·71 | 30·64 | 42· | ·219 | ·10952 |
| 75 | 11· | 20·25 | 31·25 | 42·5 | ·225 | ·1125 |

*Note.*—For miles and tenth parts of a mile, the resistance is found by multiplying the number of tenths by one-tenth the difference between the two nearest mileages, and adding it to the resistance for the whole number.

Thus for the train resistance for 61·3 miles per hour, take for 62 miles 23·96 – 23·45 for 61 miles an hour = $\frac{\cdot 51}{10} \times \cdot 3 + 23\cdot 45 =$ 23·60 ℔s. per ton; and in like manner for any other resistance.

## PRACTICAL OBSERVATIONS ON RESISTANCES TO RAILWAY TRAINS, WITH AN EXPLANATION OF THE PRECEDING TABLES.

As the Resistance to Railway Trains is an important point in locomotive statistics, and has long engaged much attention amongst Engineers, this Paper will be appropriately closed by giving an outline of the present position of the question.

### RESISTANCES ON THE NARROW GAUGE.

In 1846, an able Paper 'On the Resistances to Railway Trains at Different Velocities,' by Mr. Wyndham Harding, was read before the Institution of Civil Engineers, showing, from carefully selected experiments, the resistances to trains at different velocities, mostly on the narrow gauge.

Table IX. is taken from his Paper, giving only the practical results. In Mr. Harding's Paper, the Table contains very full explanatory data to each experiment, which is not necessary for general information; but those who are desirous of fully investigating the subject for themselves should refer to the original Paper for full details of the summary given in the present Table.

The formula based on these experiments, furnished by Mr. Scott Russell, was adopted by Mr. Harding "simply as an empirical formula, in order to see how far it agreed with the facts furnished by experiments made, as has been explained, by different persons at different times," and is thus described by Mr. Harding.

"The formula is very simple, and is based on the doctrine of the causes of resistance to the advance of railway trains being divisible into three classes.

"The first class of resistance is what is understood by friction, and is constant at all velocities.

"The second class is what is understood by frontage resistance, and increases as the square of the velocity in miles per hour, the resistance at one mile per hour being $\frac{1}{400}$ lb. per square foot of frontage.

"The third class of resistances may be termed, for want of a better word, resistances from concussions: the existence of such a class of resistances is indicated by the concussions and vibrations clearly perceived in a train in rapid motion. This class of resistances is held to vary in the simple ratio of the velocity.

"Calling the friction 6 lbs. per ton, the number of tons weight of the train $= T$, the velocity of the train in miles per hour $= V$, the resistance per square foot of frontage at 1 mile per hour $= \cdot 0025$ lb.; the resistances from concussions in pounds per ton of the load at 10 miles per hour and above $= \frac{V}{3}$,* the number of square feet in the frontage of the train $= N$; the formula giving the resistance in pounds per ton (of the weight of the train) is

$$6 + \frac{V}{3} + \frac{(V^2 \times \cdot 0025 \times N)}{T}.$$

"The results which this formula gives are shown in the last column of the Table. When an engine runs with a train, the friction of the engine is taken at 15 lbs. per ton of its weight.

"It will be seen that the results of the formula are somewhat higher than those of the experiments at the lower velocities, for which it is not difficult to account. In the higher range of velocities, where the formula is better tested, its agreement with the experimental results is very close.

"It appears that it applies well to passenger trains from 20 tons to 64 tons weight, and from 30 to 60 miles an hour.

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* "The divisor 3 is assumed."

"The Table (No. X.) affords the means of readily obtaining the resistances in ℔s. per ton (according to this formula) of trains of passenger carriages travelling at any speed between 10 miles and 61 miles per hour."

The method of applying this formula and Table No. X. will be best explained by examples.

Having the velocity, weight in tons, and frontage in square feet, given,—to find the resistance.

1st. Multiply the weight in tons by 6 ℔s., for friction resistance.

2nd. Multiply one-third of the velocity by the weight of the train in tons, for the concussion resistance.

3rd. Multiply the square of the velocity by ·0025 ℔., and multiply that product by the number of square feet of frontage, for the atmospheric resistance.

4th. Add together these three resistances, and divide the sum by the weight of the train in tons, which will give the resistance in ℔s. per ton.

*Ex.*—Taking a train (see Table No. IX.) of $21\frac{1}{2}$ tons, with a frontage of 60 square feet, and a velocity of 35 miles per hour,—required the resistance in ℔s. per ton?

$$\begin{array}{lll}
 & \text{℔s.} & \\
\text{Weight } 21{\cdot}5 \times 6 \;.\;\;.\;\;. & = 129 & = \text{friction resistance.} \\
\text{Velocity } \frac{35}{3} \times 21{\cdot}5 \;.\;\;. & = 249{\cdot}4 & = \text{concussion resistance.} \\
\text{Frontage } 60 \times {\cdot}0025 \times 35^2 & = 183{\cdot}7 & = \text{atmospheric resistance.}
\end{array}$$

$$\frac{\text{Total resistance} = 562{\cdot}1}{\text{Weight in tons} = \;\;21{\cdot}5} = 26{\cdot}1 \text{ ℔s. per ton.}$$

*To find the horse-power of this engine.*—Multiply the total resistance (just found) by the velocity of the train in feet per minute, and divide by 33,000, which will give the horse-power.

By Table No. I.—At a speed of 35 miles an hour, the velocity is 3080 feet per minute: hence total resistance $= \frac{562{\cdot}1 \times 3080}{33000} = 52{\cdot}46$ horse-power.

By Table No. X. this operation is readily performed.

Taking the same data as last example, and referring to the Table for 35 miles an hour, we find it is not given; but the mean between 34 and 36 miles will be sufficiently correct for our purpose, and which gives 17·6 ℔s. for friction and concussion resistance. For atmospheric resistance the mean is 30·6 ℔s. per square foot. Hence $\frac{30{\cdot}6 \times 60}{21{\cdot}5} = 8{\cdot}5$ ℔s. per ton for atmospheric resistance, which, added to 17·6 ℔s., gives 26·1 ℔s. per ton of resistance, as before.

For horse-power, $\frac{26{\cdot}1 \times 21{\cdot}5 \times 3080}{33000} = 52{\cdot}46$ horse-power, as before.

This Table, therefore, facilitates the various calculations of resistances as found by Mr. Scott Russell's formula.

With Mr. Wyndham Harding's kind permission, Tables IX. and X. are selected from his Paper; and to prevent misunderstanding, it will be best to quote his own observations thereon. He says, "Engineers are again reminded, that the resistances of which the present Paper treats must be understood to be the resistances, in calm weather, of engines and carriages of the ordinary construction, in good repair, on a railway also in good repair.

"In actual practice, various circumstances will arise, as side winds, want of repair, or adjustment in the carriages or road, sharp curves, &c.; all which tend to make the resistances more than the experiments show."

### RESISTANCES ON THE BROAD GAUGE.

The last experiments made to ascertain the resistances to railway trains at different velocities were conducted by Mr. D. Gooch, on the Bristol and Exeter Railway, in order that he might answer the queries sent to him, and also to other Engineers, by the Railway Commissioners.

Messrs. Stephenson, Locke, M'Connell, and Trevithick, in their replies on this point, referred to Mr. Wyndham Harding's Paper on resistances to railway trains, which has been explained; but Mr. D. Gooch instituted and carried out that valuable set of experiments published with full details in the Appendix to the Railway Commissioners' Report to the House of Lords on Railway Communication between London and Birmingham.

In these experiments are given, separately, the resistance due to the train, and the resistance due to the engine and tender preceding the train. This is an important step towards obtaining an accurate formula for estimating the resistances to railway trains of different weights and at different velocities.

The advantage of separating the engine and tender resistance from that of the train, in any general formula, will be evident by comparing its effects per ton on trains of different weights.

For instance, taking two of the experiments in Table XI., at nearly the same velocity, but with different loads, we have for 100 tons, at 56·6 miles per hour, the engine and tender resistance $= \frac{2469}{149{\cdot}2}$ ℔s. $=$ 16·5 ℔s. per ton over the gross weight of the train. For the 50 tons train, at 58 miles an hour, the engine and tender resistance $= \frac{2085}{100{\cdot}7}$ ℔s. $=$ 20·7 ℔s. per ton over the gross weight of the train.

A similar effect is produced on trains at low velocities. For 100 tons, at 21·1 miles an hour, we have engine and tender resistance $= \frac{807}{150{\cdot}8}$ ℔s. $=$ 5·3 ℔s. per ton; and for 50 tons, at 21·8 miles per hour, the engine and tender resistance $= \frac{973}{98{\cdot}5}$ ℔s. $=$ 9·8 ℔s. per ton.

It appears from this that the effect is about 4·2 ℔s. per ton for the high velocity, and 4·5 ℔s. per ton at the low velocity, greater resistance from the engine, over the weight of the light train than over that of the heavy one.*

The great amount of power absorbed by the engine itself is quite prominent throughout the whole of these experiments. Column 4, Table XI., shows the resistance of the engine and tender considered as part of the train. Column 5 shows the estimated resistance of the machinery of the engine after deducting the resistance due to the engine and tender at the ratio of the train resistance.

The resistance of the machinery, however, admits of explanation. The connecting-rods are of considerable weight, and freely suspended between the crank and cross-head. With a 2-feet stroke (that of the 'Iron Duke' class), the heavy end of the connecting-rod travels through a space of 6·283 feet each revolution of the wheel, and for two connecting-rods gives 12·566 feet for each revolution; while the other ends of the connecting-rods travel about 8 feet during the same time. 72 miles an hour is about the maximum speed of this class of engines with a moderate load. The driving wheels are 8 feet diameter, and the stroke being 2 feet, gives the average velocity of the piston as 1000 feet per minute. The irregular motion of the crank will, however, make the velocity of the piston in the centre of the cylinder about 1500 feet per minute. The crank has at the same moment its greatest power, and the piston its greatest velocity, when the unbalanced centrifugal power and momentum of the connecting-rod and crank change the direction of their forces. For instance, if the crank be on the top centre, and suppose that part of the connecting-rod, with the crank to which it is attached, weighs no more than 560 ℔s., we have this weight descending in a forward direction for 1·57 ft., and for the next 1·57 ft. descending in a backward direction, at an average velocity of 1575 feet per minute. Now if the weight is multiplied by the velocity, it gives 882,000 lbs. of mixed forces of momentum of the connecting-rod and centrifugal force of the crank, changing the direction of its forces no less than eight times for each revolution of the driving wheel. As there are two connecting-rods and cranks in motion to produce one revolution, consequently it requires two downward and forward, two downward and backward, two upward and backward, and two upward and forward changes of the direction of the forces generated by the combined movements of the crank and connecting-rod. The dotted lines of the annexed diagram will show what is meant by the different directions of the centrifugal force of the connecting-rod and crank. The arrows indicate the direction in which the crank is moving, and the letters the direction of the forces. D F = downward and forward. D B = downward and backward. U B = upward and backward. U F = upward and forward.

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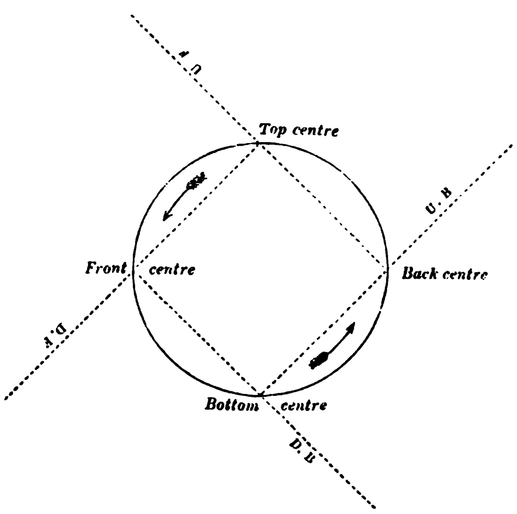
* In the comparative Diagram of Resistances accompanying Mr. D. Gooch's experiments this is clearly shown, and is the reason why the lines of resistance of the 50 tons trains are higher than those for the 100 tons trains.



The above estimate and diagram are given for illustration only, as it requires correct data to estimate the resistance accurately; but they will give an idea of the nature of the resistance to be overcome at high velocities, above that of the blast and slides.

When a locomotive piston travels at the average rate of 1000 feet per minute, the power absorbed by the unbalanced momentum of the machinery must be very considerable, and, far more than the resistance of the atmosphere, limits the velocity attainable by any class of engines. Practical men have long sought to find a remedy for this unbalanced momentum; and the higher the velocity, the more desirable it is that the piston and rod, the connecting-rod and slide-valves, should all be properly balanced.

Mr. Heaton, Mr. D. Gooch, and Mr. M'Connell, are, it is understood, now engaged with experiments on this subject; and it is to be hoped they will be successful in devising a practical remedy for the present unbalanced machinery of a locomotive engine.

In practice it is found that the height of the driving wheel, other circumstances being alike, decides the average speed for each class of engines. This may be taken as proof that it is the resistance of the machinery which limits the speed, and that by giving it more ease, an increased standard of velocity is attained, corresponding to the ease given. Accordingly, Mr. Stephenson, in his 8-wheeled class of engines, adopts a 7-feet wheel, and Mr. Crampton, in his patent 8-wheeled engines, still further carries out the same principle by adopting an 8-feet wheel with a low centre of gravity, both necessary and desirable means for obtaining steadiness, speed, and safety on any railway.

Those who have travelled on locomotives at high velocities could scarcely fail to notice the rapid movements of the working parts of the engine without reflecting on the great power required to produce and sustain that movement itself, independent of load. To them, the above explanation of the supposed cause of resistance will be clearly understood. To others, who may not have had such an opportunity, an example will best explain it, and perhaps be the means of drawing both theoretical and practical attention to ascertain the value of such resistance, including the slide-valves, the blast-pipe, and compressed steam at high speeds. Travelling lately from Didcot to Paddington on the 'Emperor' locomotive (one of the 'Iron Duke' class), the distance of 53 miles was run, with the ordinary express train, in 49½ minutes. The 'Great Britain,' with which these experiments were made, is said to have run the same distance in 47½ minutes with the express train. The speed, therefore, was not an extreme one throughout, as no effort was made to obtain a high speed, but the engine was worked in the ordinary way.

The day was calm, but cloudy, and a higher speed was expected along the good straight road from Twyford to Maidenhead, but it was comparatively little increased. The steam was blowing off, and the fire-door was opened to check it. There was no side wind, for it was in a cutting, and the only atmospheric resistance was that due to the velocity. The load was about 60 tons: the speed was at the rate of from 70 to 72 miles an hour; a high speed, it is true, but the question immediately suggested itself,—Why, under such favourable circumstances, was the speed not higher?—eliciting only another question,—Where lay the limiting resistance to a higher speed? for there was clearly an equilibrium between the power and the resistance. The answer which occurred was this,—that it was the unbalanced machinery, the unbalanced slide-valves, the effects of the blast, and of the steam compressed in the cylinder, which mainly limited the speed to 72 miles an hour.

If this be a correct view of the limiting cause of the speed of locomotive engines, it follows that increased velocities must be sought for by giving greater ease to the machinery, along with increased boiler and cylinder power. The investigation of Mr. D. Gooch's experiments seems to confirm this conclusion, and it is submitted now with the view of drawing the attention of future experimenters to determine its value as a principal resistance to railway trains at high velocities.

In submitting, therefore, an abstract of Mr. D. Gooch's experiments, the practical question has been kept clear from all other considerations, and the indicator and dynamometer resistances only investigated: these, being taken by competent and impartial persons, are valuable as data of resistances to railway trains under similar circumstances. The shortness of the distance experimented upon is the only draw-back, but it renders the minutest error visible in the tabulated results in the Report to the House of Lords; and where these were observable, they have been omitted in taking the averages given in Table XI. As the weather was very unfavourable for experimenting when they were made, they may be fairly regarded as giving average resistances on a calm day, and every thing in good working order.

In Table XI. the indicator and dynamometer resistances are given separately for the engine and train, and combined for the gross load. The first twelve columns are practical, and the headings will explain them: the next two columns are explanatory of the circumstances occurring when the experiments were made: the last nine columns are theoretical, calculated from a formula which will now be explained.

The resistance for the engine and tender, it will be observed, increases in the ratio of the velocity, regulated, however, by the load. Commencing at 5½ lbs. per ton at 1 mile an hour, the ratio of increase is ·5 lb. per mile per hour. From this we have the velocity × ·5 + 5 = resistance of engine and tender per ton for their own separate resistance. The additional resistance to the engine from the atmosphere and load is taken as the square of the velocity × by the weight of the train, and by ·00004, to be added to the preceding for the resistance per ton, and multiplied by their weight for the total resistance of the engine and tender in lbs. It may be thus stated:

Velocity $\times \cdot 5 + 5 +$ velocity$^2$ $\times$ weight of train $\times \cdot 00004 =$ engine and tender resistance per ton.
By this formula columns 19 and 22 are calculated.

The atmospheric resistance is taken as increasing in the ratio of the square of the velocity in miles per hour, regulated by the bulk of the train.

Messrs. W. Harding* and D. Gooch have both adopted Pambour's theory of frontage as the measure of atmospheric resistance. Regarding, however, the experiments made by Dr. Lardner for the British Association as more satisfactory than those made by Pambour, and the conclusions[†] of Dr. Lardner as supported by his experiments, they have been adopted in investigating Mr. D. Gooch's experiments.

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* Mr. Harding, although adopting the frontage estimate for the atmospheric resistance to trains, yet clearly pointed out in his Paper (page 34) the objection to this mode of estimating that particular resistance. He says in conclusion, on this point,—"This objection points to the necessity of taking into account, in comparing resistances per ton of different trains, the composition of the trains, the resistances of which are being compared, especially as to their bulk or specific gravity, and other similar circumstances. It is not, however, easy to see what unit or common measure could be used in such com-

By combining the bulk and velocity together in estimating the resistance of the atmosphere, results are obtained which vary with every varying load and speed, thereby fairly representing the displacement of air by railway trains of all dimensions.

For instance, the train with which these experiments were made, as shown on the drawing accompanying them in the Railway Commissioners' Report, measures 276 feet long, which corresponds with the average length of the carriages and intermediate spaces between them. Their width is 9 feet, and height of bodies 7¼ feet: this gives $276 \times 9 \times 7\frac{1}{4} = 18009$ cubic feet of bulk for ten carriages weighing 100 tons. By rejecting the odd 9 feet, we have 180 cubic feet of bulk = 1 ton of weight of passenger carriages.

There is so little difference in the proportion of bulk to weight of carriages on both gauges, that the same ratio will, without material error, apply to both. The following average dimensions and weights, taken from Mr. D. Gooch's evidence as given in the Gauge Commissioners' Report, will show how nearly they are alike. The height of the bodies only has been taken, as any atmospheric resistance to the wheels is more properly included with friction and oscillation.

| | Average No. of passengers per carriage. | Weight of passengers, at 1½ cwt. each. | Average weight of carriages. | Average weight of loaded carriage. | Average dimensions of carriages. | | | Average bulk in cubic feet of one carriage. | Average bulk per ton. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Length. | Width. | Height. | | |
| | No. | cwts. | cwts. | cwts. | feet. | feet. | feet. | cub. ft. | cub. ft. |
| Broad gauge . . | 52 | 78 | 147 | 225 | 25½ | 9 | 7¼ | 1664 | 147·9 |
| Narrow gauge . | 21 | 31½ | 80½ | 112 | 17 | 7 | 7 | 833 | 148·8 |

The spaces between the carriages make up the difference shown by the tabular bulk per carriage, and that obtained per carriage when forming part of a train. Until a more careful inquiry shall determine a better ratio, the approximation of carriages on both gauges is so near that 180 cubic feet per ton might be tried for the narrow gauge as well as for the experiments to which it is now applied.

Independent, however, of Dr. Lardner's conclusions, it is reasonable to assume that a train of the bulk of 18,000 cubic feet would experience greater atmospheric resistance than a train of only one-tenth of that bulk. This, however, is not recognized in the frontage theory, which, to make up for its apparent deficiency, even in the Comte Pambour's experiments, included wheels, the eddying between the carriages, and (if it were fully carried out) should also have included the resistance from every open carriage window in a train. By taking the bulk for the measure of atmospheric resistance, it embraces all these in a much more satisfactory manner than can be done separately, and for these reasons it has been adopted at this time in investigating the broad-gauge experiments.

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parisons which would be so convenient or intelligible to Engineers as the ton weight." This unit I have endeavoured to supply by the actual data of 180 cubic feet of bulk being equal to one ton in weight for passenger carriages on the broad gauge. The same unit will be nearly correct for the narrow-gauge passenger carriages also.

[†] After making a number of experiments with various sized and shaped vehicles, Dr. Lardner's conclusions on atmospheric resistance were,—

> "That the shape of the front or hind part of the train has no observable effect on the resistance.
>
> "That the spaces between the carriages of the train have no observable effect on the resistance.
>
> "That the train, with the same width of frontage, suffers increased resistance with the increased bulk or volume of the coaches."

The atmospheric resistance is therefore taken to increase in the ratio of the square of the velocity in miles per hour × by the bulk of the train in cubic feet, and by ·00002 as a co-efficient per ton of train. By this data column 16 is calculated.

The friction resistance is taken at 6 ℔s. per ton, as seen in column 15.

The oscillatory resistance is taken as increasing in the ratio of $\frac{1}{15}$th the velocity × by the weight of the train only. Column 17 is calculated by this data.

For what reason experimenters separate these two last resistances does not clearly appear. They are evidently the same resistance, increasing in the ratio of the velocity only. Oscillatory resistance is mainly the increased friction of the axle bearing against the collars of the axle, consequent upon the transverse vibrations at high velocities. It is practically and forcibly exhibited in the wearing away of the ends of the axle bearings, which in many instances wear more rapidly than the top part where the weight rests upon. The bearing has then to be lengthened, or thrown aside as old metal.

Such practical evidence is the strongest proof that the axle friction is not constant at all velocities, but increases with the increasing velocity, and should be so estimated generally, as it has been done in Table No. XII. and in the Diagram of Resistances.

In Table XI. they have, however, been given separately, the better to test the formula, and also as an unit to start from, adopted by former experimenters and investigators of resistances to railway trains.

The formula, therefore, by which the estimated resistances in Tables XI. and XII. are calculated is submitted as an empirical one only, and embraces,—

1st, The engine and tender resistance, increasing in the ratio of the velocity for their own resistance, and in the ratio of the square of the velocity, regulated by the load, for atmospheric and load resistance.

2ndly, The atmospheric resistance of the train, increasing as the square of the velocity, regulated by the bulk of the train.

3rdly, The oscillatory resistance, increasing in the ratio of the velocity (estimated at one-fifteenth), regulated by the load.

4thly, The friction resistance (for the reasons given, estimated at 6 ℔s. per ton), regulated by the load.

It is, therefore, simple in its elements, and may be thus expressed.

Calling the weight of the train in tons = T, the friction of the train per ton = 6 ℔s., the bulk of the train in cubic feet = B, the weight of the engine and tender = E, the velocity = V; we have for a formula by which to estimate the resistances separately,

$$\begin{aligned}
&E \times (V \times {\cdot}5 + 5 + V^2 \times T \times {\cdot}00004) &&= \text{engine and tender resistance in ℔s.}\\
&V^2 \times B \times {\cdot}00002 \quad . \quad . \quad . \quad . \quad . &&= \text{atmospheric resistance in ℔s.}\\
&\frac{V \times T}{15} \quad . \quad . \quad . \quad . \quad . \quad . \quad . &&= \text{oscillatory resistance in ℔s.}\\
&T \times 6 \quad . \quad . \quad . \quad . \quad . \quad . \quad . &&= \text{friction resistance in ℔s.}
\end{aligned}$$

These separate resistances, being added into one sum and divided by the gross load, give the estimated resistance per ton. Briefly it would stand thus,—

$$E \times (V \times {\cdot}5 + 5 + V^2 \times T \times {\cdot}00004) + (V^2 \times B \times {\cdot}00002) + \frac{V \times T}{15} + \frac{T \times 6}{E.T.} = \text{resistance per ton.}$$

The theoretical resistances given in Table No. XI. are from the above formula, and their general agreement with the (somewhat irregular) practical results is satisfactory.

Table XII. is also drawn up from this formula, to facilitate estimating the resistances of trains under similar circumstances on a level line, a calm day, and engine, carriages and road in good working order.

The Diagram * shows the same resistances as Table XII., exhibiting them separately for the engine and

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* Owing to the small scale of the Diagram, there is some irregularity in the train lines D, which is accidental, and not the result of the theory; but Table XII. gives them correctly in figures.

train. For the reasons already mentioned, lines of resistance for the engine and tender, with various loads, are also shown separately. Being divided into tenths of an inch each way, either miles or ℔s. can be counted without the aid of a scale or instruments. The base line indicates the velocity in miles per hour. The vertical lines indicate the ℔s. per ton at the point intersected by the line of resistance. Each tenth of an inch along the base line represents one mile, and each tenth of an inch on the vertical lines represents 1 ℔.

As the additional resistance from the atmosphere and load on the engine and tender is only 2·25 ℔s. per ton of the train, at a velocity of 75 miles an hour, it is shown in a separate diagram, where the miles on the base line are represented by tenths of an inch; but the ℔s. on the vertical lines by hundredths of an inch. This admits the resistance in hundredths of a ℔. per ton to be counted without the aid of instruments. The resistance in ℔s. per cubic foot of bulk is one-half of this additional resistance.

The results arrived at in this investigation, and embodied in the diagrams, demonstrate the necessity of a more perfect mechanical construction of the locomotive engine, and fully explain what has been stated regarding the vast amount of power absorbed by the engine itself.

The application of the Formula and Tables will now be explained by examples, as before.

Having the velocity, weight of engine and tender in tons, weight of train in tons, and bulk of train (exclusive of engine and tender) in cubic feet, given,—required the engine and tender resistance, the atmospheric resistance, the oscillatory resistance, and the friction resistance, separately; also per ton of the gross load?

1st, Multiply the velocity by ·5, and to the product add 5 for the friction of the axles and machinery of the engine. For the additional resistance of the atmosphere and load on the engine, multiply the square of the velocity in miles per hour by the weight of the train in tons, and by ·00004. Add these together for the resistance in ℔s. per ton of the engine and tender, and multiply by their weight in tons for their total resistance in ℔s.

2ndly, Multiply the square of the velocity by the bulk of the train (excluding the engine and tender), and by ·00002, for the atmospheric resistance in ℔s. due to the train.

3rdly, Multiply the velocity by the weight of the train, and divide by 15, for the oscillatory resistance of the train in ℔s.

4thly, Multiply the weight of the train in tons by 6, for the friction resistance in ℔s.

5thly, Add into one sum these resistances, and divide by the gross weight of the train in tons, for the resistance in ℔s. per ton of the gross load.

*Ex.*—Taking a train of 100 tons, engine and tender of 49·2 tons, velocity 56·6 miles per hour, and bulk 18,000 cubic feet,—required the separate resistances, and the resistance per ton of the gross load? (See Table XI.)

For the engine and tender resistance we have

$$56{\cdot}6 \times {\cdot}5 + 5 + 56{\cdot}6^2 \times 100 \times {\cdot}00004 = 46{\cdot}1 \text{ ℔s. per ton} \times 49{\cdot}2 = 2268{\cdot}12 \text{ ℔s.}$$

resistance for the engine and tender.

In order to test the formula, it will be contrasted, throughout this example, with the experimental results. On referring to the Table it will be observed that the experimental resistance is greatest by 201 ℔s. As the train was, however, subjected to a 'strong side wind,' the whole of the experimental results are greater than those found by the formula. In other instances the resistances found by the formula are greatest. It is, therefore, by its general agreement with the whole of the experiments that it should be tested, and not by any one experiment. The example now taken shows a total difference of 251 ℔s.; 201 ℔s. of which are due to the engine, or about 4 ℔s. per ton on the engine and tender weight, showing that although the resistance of the engine is estimated at a high rate, it does not appear to be in excess for ordinary contingencies, being too low for the effects of a side wind on the engine.

For the friction resistance we have 100 × 6 = 600 lbs. This, taken from the dynamometer resistance of 2180 lbs., leaves 1580 lbs. to be divided between the atmospheric and oscillatory resistances, and so limits the inquiry as to admit of no great error in estimating them.

For oscillatory resistance we have $\frac{56·6 \times 100}{15} = 377·3$ lbs., which, taken from 1580, leaves 1202·7 lbs.

For atmospheric resistance we have $56·6^2 \times 18000 \times ·00002 = 1153·28$ lbs., or 49·4 lbs. less resistance for the train by formula than by the dynamometer, being within half a pound per ton of the weight of the train, although exposed to a side wind.

Stated concisely, these calculations would stand thus,—

| | lbs. | Resistances. |
|---|---|---|
| $56·6 \times ·5 + 5 + 56·6^2 \times 100 \times ·00004 \times 49·2$ | = 2268·12 | = engine and tender. |
| $100 \times 6$ | = 600 | = friction. |
| $\frac{56·6 \times 100}{15}$ | = 377·3 | = oscillatory. |
| $56·6^2 \times 18000 \times ·00002$ | = 1153·28 | = atmospheric. |

$$\text{Gross weight of train} = \frac{4398·7}{149·2} = 29·48 \text{ lbs.}$$

per ton of the gross load.

The experimental resistance was 31·16 lbs. per ton, the estimated resistance 29·48 lbs., or 1·68 lbs. per ton of the load less than the former; a near approximation to a train having the retarding influence of a side wind to contend against, with four-fifths of this difference due to the engine.

The formula, therefore, from which this estimate, Table XII., and the Diagram, are drawn up, appears to be sufficiently accurate for general reference for engines and trains on the broad gauge of the class experimented with by Mr. D. Gooch.

As these experiments were made with an engine and tender weighing about 50 tons, with 8-feet driving wheels, the line of engine and tender resistance per ton on the diagram will only apply to engines of the same general class and weight. The greater ease to the machinery of an engine with 8-feet driving wheels over that of an engine with 5, 5½, or 6-feet wheels, is necessarily very considerable, as seen below.

By Table VI. the revolutions of an 8-feet wheel per mile are 210·1 times,—of a 6-feet wheel 280·5 times,—of a 5½-feet wheel 305·6 times,—and of a 5-feet wheel 336·3 times; consequently, for a run of only 50 miles, it gives

| | Revolutions of the driving wheel. | | No. of the cylinders of steam to exhaust through the blast-pipe. |
|---|---|---|---|
| For an 8-feet wheel | 210·1 × 50 = 10505 | or | 42020 |
| ,, 6-feet ,, | 280·5 × 50 = 14025 | or | 56100 |
| ,, 5½-feet ,, | 305·6 × 50 = 15280 | or | 61120 |
| ,, 5-feet ,, | 336·3 × 50 = 16815 | or | 67260 |

As the resistance of the machinery, slides, and blast increases rapidly in proportion to the velocity of the piston and the number of exhausts of steam per minute, the line which indicates the $\frac{1}{50}$th of the resistance due to the complete machine for generating power, with its machinery moving ⅕, ½ or ⅗ slower than the working parts of another power-producing machine, it is evident would not indicate $\frac{1}{50}$th of the resistance due to the more rapid moving machinery of a lighter machine. The ratio of the resistance for the latter machine would therefore be much higher than $\frac{1}{50}$th of that due to the 'Great Britain' class of engines.

That the machinery of the 'Great Britain' works freely is beyond question. Twice, with the ordinary express trains, this engine has maintained an average velocity of nearly 67 miles per hour over the 53 miles from Paddington to Didcot, including starting from a state of rest until coming to the stopping platform again. The one trip was up gradients averaging 4 feet per mile, the other down the same gradients. The trip up the gradients is generally run in least time: this arises from having to reduce the speed quite low on the down trip, nearly a mile from Paddington, which thus takes much longer time to run over than is fairly due to stopping at any other station.

Sixty-seven miles an hour is about the maximum average velocity of the 'Iron Duke' class of engines, the drawings of which accompany this Paper. The 'Great Britain' was made from the same drawings as the 'Iron Duke,' and the performances of the whole class are as nearly alike as those of any class of engines can be. A new class of engines of the same general construction, but with 3 inches shorter tubes and 6 inches longer fire-box, appear from the performance of the 'Courier' (one of the new class), as reported in the *Morning Herald*, (although only newly out of the shop,) already to equal the 'Iron Duke' class. When the 'Courier' class has been in work for some months, it is probable that they will reach a maximum velocity of from 75 to 77 miles per hour, or an average maximum velocity of about 70 miles an hour with moderate trains. As the area of the blast-pipe of the 'Courier' class is larger by about 4 square inches than the blast-pipe of the 'Iron Duke' class, it shows that the enlarged fire-box generates the same quantity of steam with less blast; and as the increased size of the blast-pipe diminishes the compression, it so far eases the piston that a proportionally increased velocity will be attained, with less consumption of fuel, from the milder blast on the fire. This consumption is as low as from 24 to 26 lbs. of coke per mile for running 1078 miles per week with the mail trains, and that for engines newly out of the workmen's hands.

Regarding, therefore, 75 miles an hour as the maximum velocity of the best locomotive engines of the day, the Table No. XII. and the Diagram of Resistances from the formula have been carried out to that velocity only. When a higher velocity is attained it will be by some improved arrangements of the machinery, slide-valve, and blast, which would give a lower ratio of resistance throughout, and require new data to indicate the new line of resistance due to the superior arrangements of the power-producing machine.

The line of resistance, therefore, which is applicable to the 'Great Britain' class of engines, cannot be applicable to other classes of engines (irrespective of gauge), as from this investigation it appears that each different kind would have its own separate line of resistance. As there is not so great variety amongst carriages as amongst engines, the ratio of resistance for the carriages would be more permanent than it can be for engines so variously constructed.

The data for indicating the lines of resistance for locomotives of various decriptions are extremely limited. The Comte De Pambour clearly saw, and ably pointed out, the necessity of estimating the resistances separately, as has been done in this Paper. His experiments on the friction of loaded and unloaded engines were very good as far as they went, and only require to be fully carried out, to give the data necessary to lay down lines of resistance for any particular class of locomotives.

In the Diagram of Resistances the lines A and B indicate the mean resistance the Comte De Pambour found by experiment on engines from 8 to 11 tons weight; but he gives no data by which to trace the direction of these lines. The only other avaliable data are those of two indicator experiments taken by Mr. D. Gooch, at 10 and 20 miles an hour. The line marked C on the diagram shows the resistance per ton indicated by these experiments. It is not given for calculating the resistance of the 'Ixion' class of engines, but is given along with the resistances indicated by the Comte De Pambour's experiments, as sufficient to show that new experimental data are required to determine the law of resistance to locomotive engines of various descriptions on both gauges. One inference which may be drawn from the highest speed of the 'Iron Duke' and other classes of engines seems to be this, that with a load, and at a velocity of 1000 feet per minute of the piston, locomotives have reached their maximum velocity as they are at present constructed. This point, however, should be investigated by future experimenters, in order to

# DIVISION A.—LOCOMOTIVE ENGINES.

## SECOND PAPER.

# EXPRESS CARRIAGE ENGINE.

BY JAMES SAMUEL, C.E.

OF THE EASTERN COUNTIES RAILWAY.

THE annexed Drawings represent a plan, elevation, and section of a small Locomotive, lately introduced on the Eastern Counties Railway by Mr. James Samuel, the Resident Engineer.

This carriage engine was constructed for the purpose of inspecting the lines, and thereby avoiding the great expense of employing express engines of the usual description.

The total length of the carriage is 12 feet 6 inches, including machinery, water tank, and seats for seven passengers, all on one frame, which is hung below the axles, and is carried on four wheels, 3 feet 4 inches in diameter. The floor is within 9 inches of the level of the rails.

It is propelled by two cylinders, 3½ inches in diameter and six-inch stroke, placed on each side of the boiler, and acting on a cranked axle.

The boiler is cylindrical, placed vertically, and is 1 foot 7 inches in diameter by 4 feet 3 inches in height. It contains a fire-box, 16 inches in diameter by 14 inches in height, with thirty-five tubes, 3 feet 3 inches long by 1½ inch in diameter, giving 5½ feet of heating surface on the fire-box, and 38 feet on the tubes.

The engine is fitted complete with link motion, feed-pumps, &c. The water tank is placed under the seat, and will contain 40 gallons.

This carriage is capable of conveying seven persons at a rate of 30 miles an hour: it has at times attained a speed of 44 miles. The comsumption of coke is only 3¼ lbs. per mile, and the weight of the whole machine does not exceed 25½ cwt., including coke and water.

From a statement kept of the weekly working of this engine, it appears that the number of miles run during the half-year ending 4th July was 5526, and the quantity of coke consumed was 7 tons 9 cwt., being at the rate of about 3 ℔s. per mile.

The result of experiments which have been made with this engine has been so satisfactory that it has been resolved to adopt the principle in the construction of steam carriages for working passenger and express trains on Branch Lines, by which a considerable saving may be effected in the consumption of coke, and also in the expense of repairs, both of the carrying stock and engines, and of the way and works of the line.

London, August, 1848.

deduce from it some general law applicable to the velocity of the piston, and its relation to the highest speed of locomotives of various constructions.

From what has been said, it will be clearly understood that the resistances indicated by the formula are those due to engines of the class of the 'Iron Duke,' and carriages of the ordinary construction on the Great Western Railway, both in good working order, on a calm day, and on a level railway in good repair. For gradients they require to have the resistance per ton due to the incline, as in Table V., added to the resistances given in Table XII. or in the Diagram of Resistances. For gradients not in Table V. the resistance due to the incline may be found by dividing the lbs. in a ton (2240 lbs.) by the ratio of the rise in feet. Thus, if the gradient be 1 in 700 feet, we have $\frac{22400}{700} = 3{\cdot}2$ lbs. per ton as the resistance due to the incline, to be added to the resistance given by the formula.

With these observations, we now proceed with the examples.

By Table XII. the resistances given by the formula are readily calculated.

*Ex.*—Required the total resistance, and the resistance per ton of the gross load, for a train of 60 tons, engine and tender 50 tons, bulk of train 10,800 cubic feet, and velocity 50 miles per hour, on a level railway? Referring to the Table, opposite '50 miles per hour' is 30 lbs. for the engine and tender resistance, and ·1 lb. for the additional resistance to the engine from the atmosphere and load per ton of the train, or ·05 per cubic foot of bulk of the train. This gives for engine and tender resistance 60 × ·1 = 6 lbs., to be added to the 30 lbs. due to the engine and tender alone, = 36 lbs. per ton as the engine and tender resistance. For friction and oscillation, the resistance opposite '50 miles' per hour is 9·33 lbs., and for the atmosphere 9 lbs.; hence

Engine and tender of 50 tons × 36 lbs. = 1800 lbs. = engine and tender resistance.
Train of 60 tons × 9·33 „ = 559·8 „ = friction and oscillation resistance.
„ of 60 tons × 9·0 „ = 540 „ = atmospheric resistance.

$$\frac{\text{Total resistance}}{\text{Gross weight of train}} = \frac{2899{\cdot}8}{110} = 26{\cdot}36 \text{ lbs. per ton of the gross load.}$$

Or thus by bulk:

Engine and tender of 50 tons × 36 lbs. = 1800 lbs.
Train of 60 tons × 9·33 „ = 559·8 „
„ bulk of 10,800 cubic feet × ·05 „ = 540 „

$$\frac{\text{Total resistance}}{\text{Gross load}\ .\ .\ .} = \frac{2899{\cdot}8}{110} = 26{\cdot}36 \text{ lbs. per ton, as before.}$$

By taking the total resistance of the train at once it shortens the calculation.

Thus, 50 × 36 = 1800
And for total resistance by Table we have 18·33 lbs.; and 60 × 18·33 = 1099·8

$$\frac{\text{Total resistance}\ .\ .\ .\ .\ .\ .\ .\ .\ .}{\text{Gross load}\ .\ .\ .\ .\ .\ .\ .\ .\ .} = \frac{2899{\cdot}8}{110} = 26{\cdot}36 \text{ lbs., as before.}$$

For the resistance to the above train on a gradient of 1 in 100, requires to be added the gravity due to the incline, which by Table V. is 22·4 lbs. per ton; therefore 26·36 + 22·4 = 48·76 lbs. as the resistance per ton of a gross load of 110 tons, up a gradient of 1 in 100, at 50 miles an hour.

The Diagram of Resistances greatly facilitates the calculation of the resistances found from the formula, and, if constructed on a large scale, would do so with sufficient accuracy for all ordinary purposes.

*Ex.*—Taking the same data as last example,—required the resistance in lbs. per ton on a level railway, and calm day?

The velocity being 50 miles and the train 60 tons, by referring to the Table, and following the

'50 miles' vertical line until it intersects the '60 tons engine and tender' line, we have 36 ℔s., which, multiplied by the weight of the engine and tender, 50 tons, = 1800 ℔s. Again, following the '50 miles' vertical line until it intersects the train line of resistance, we have $18\frac{1}{3}$ ℔s., say 18·33 ℔s. × 60 tons = 1099·8 ℔s. + 1800 ℔s. = 2899·8 ℔s. total resistance, divided by 110 tons (the gross load) = 26·36 ℔s.

Another example will illustrate the facility with which this Diagram of Resistances can be applied.

*Ex.*—Required the resistance of a train of 70 tons, engine and tender 50 tons, at 60 miles an hour, on a level, also the resistance on a gradient of 1 in 800?

By the Table we find the '60 mile' vertical line intersects the '70 ton' engine and tender line at 45 ℔s., and the train line at nearly 23 ℔s. (by calculation 22·96 ℔s.);

Therefore, Engine and tender of 50 tons × 45 ℔s. = 2250 ℔s.
and Train of 70 tons × 23 ℔s. = 1610 „

$$\text{Divided by the gross load} = \frac{3860}{120}\ \text{tons}, = 32{\cdot}16\ \text{℔s. per ton, on a level.}$$

For the gradient, by Table V. the resistance due to 1 in 100 is 22·4 ℔s.; hence 22·4 ÷ 8 = 2·8 ℔s. as the resistance per ton due to a rise of 1 in 800; and 32·16 + 2·8 = 34·96 ℔s. per ton on a gradient of 1 in 800.

### RESISTANCE OF THE BLAST-PIPE.

As the blast-pipe is a distinct and important part of a locomotive engine, we will now endeavour to ascertain its practical value for engines of the class of the 'Great Britain.'

The resistance of the blast-pipe was deducted from all the experiments recorded in Table XI. In addition, therefore, to the resistances already considered, the steam has to overcome that of the blast-pipe. The indicator cards taken during these experiments, as given in Table XIII., supply valuable data of the relations between front and back pressure, also between the load, the velocity, and the pressure on the piston. From this record of 67 indicator cards, it appears that the back pressure follows the ratio of the mean pressure on the piston, regulated by its velocity; and that whilst a heavy load increases the mean pressure on the piston, the per centage of back to front pressure remains nearly the same as with lighter loads at similar velocities.

The pressure of the steam in the boiler will regulate that of the steam admitted to the cylinder until the communication is cut off by the slide-valve. The degree of expansion of the steam so cut off will then regulate the mean pressure on the piston so that it may be generated under a pressure of 90 ℔s. in the boiler, and only averaging 20 ℔s. in the cylinder. It is therefore the ℔s. of steam cut off in the cylinder which regulate the resistance of the blast-pipe; for if it be expanded during three-fourths of the stroke, a low back pressure will result; but if only expanded during one-fourth of the stroke, a higher back pressure will be produced,—so that the mean pressure on the piston indicates the degree of expansion in the cylinder. The general increase being nearly in the ratio of the square of the pressure, it has been so estimated in the law for calculating the resistance of the blast-pipe. The velocity of the piston in feet per minute, the orifice of the blast-pipe, and the capacity of the cylinder, are the remaining elements of that law.

The formula (from which the theoretical columns of back pressure in the Table have been calculated) embraces all these in the following manner:

To the square of the mean pressure in ℔s. per square inch + the velocity of the piston in feet per minute, × by the ratio of the capacity of the cylinder to the area of the orifice of the blast-pipe, and by ·00001, for the back pressure in ℔s. per square inch against the piston. If we call the pressure P, the velocity V, the ratio of the cylinder and blast-pipe R, the formula would stand thus:

$$P^2 + V \times R \times {\cdot}00001 = \text{back pressure in ℔s. per square inch.}$$

It is submitted as an empirical law only, limited at present to engines of the class of the 'Great Britain,' until future experiments shall determine whether it is applicable to other classes of locomotives. Its application is simple, and will now be explained by an example.

*Ex.*—Let a locomotive engine have cylinders 18 inches diameter, 2-feet stroke, blast-pipe 5 inches diameter, driving wheels 8 feet diameter, velocity 56·6 miles per hour, mean pressure on the piston 79·4 ℔s. per square inch;—required the back pressure against the piston? (See Table XIII.)

$$\begin{array}{l}\text{For capacity of cylinder we have } 18^2 \times {\cdot}7854 \times 24 = \\ \text{For area of orifice of blast-pipe we have } 5^2 \times {\cdot}7854 = \end{array} \frac{6107{\cdot}25}{19{\cdot}635} = 311$$

for the ratio between the cylinder and blast-pipe.

For the velocity of the piston we have by Table VI. 210·1 (revolutions for an 8-feet wheel per mile) ×4 = 840·4 feet travelled by the piston per mile; hence 840·4÷60=14·0 as the ratio nearly between the miles per hour of the driving wheel and the feet per minute of the piston, and which has been adopted in calculating the resistances in Table XIII.

Therefore, $(79{\cdot}4^2 + 56{\cdot}6) \times 14 \times 311 \times {\cdot}00001 = 22{\cdot}068$ ℔s. per square inch for the back pressure.

By referring to the Table it will be seen that the experimental result was 22·5, so that the formula gives a near approximation to the practical value of the back pressure for engines of the class of the 'Great Britain.' It also gives results varying with every varying ratio of cylinder to blast-pipe. Applied to some experiments made by Mr. J. Parkes,* it gives results nearly the same as he arrived at by removing the blast-pipe. From these experiments Mr. Parkes concluded—"That the counter-resistance from the blast augments and diminishes with the pressure on the piston, and that it is independent of the velocity of the piston; for in all these observations it only rose with the velocity when the pressure was increased."

The more extensive series of observations taken by Mr. D. Gooch confirm the first part of this conclusion, but show that it is modified by the velocity of the piston. As the Comte De Pambour does not give the pressure in the boiler or on the piston, during the experiments he made (regarding back pressure as due to velocity only), we cannot compare his experiments with the formula now submitted.

Mr. D. Gooch states that "in the 'Ixion' engine, the blast-pipe of which was $\frac{1}{18}$th of the area of the cylinder, with the driving wheel 7 feet in diameter, and the steam cut off at $13\frac{5}{8}$ inches of the stroke, the loss from the back pressure at different velocities was 2·1 per cent. at 7 miles an hour; 11·6 per cent. at 20 miles; 15·8 per cent. at 40 miles; and 21 per cent. at 60 miles; and the indicator cards accompanying the Experiments on the Resistance of Trains also show nearly similar results."

These cards, it has been seen, show that the back pressure increases generally in the ratio of the pressure regulated by the velocity, and that the larger the orifice of the blast-pipe is to the capacity of the cylinder, the less back pressure there will be at all velocities.

An analysis of the experiment we have mentioned, at 56·6 miles an hour, gives the following values of the separate resistances.

| Resistances of | Weight. | Mean Pressure on Piston. | Mean back Pressure. | Value of Resistances | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | In Cylinder. | | In Traction. | | In Horse-Power. | | Per Cent. | |
| | | | | Practical. | Theoretical. | Practical. | Theoretical. | Practical. | Theoretical. | Practical. | Theoretical. |
| | Tons. | ℔s. | ℔s. | ℔s. | ℔s. | ℔s. | ℔s. | No. | No. | | |
| Engine and tender. | 49·2 | | | 372226 | 342261 | 2469 | 2269 | 372 | 343 | 38·26 | 35·18‡ |
| Blast-pipe . . . | | | | 271727 | 271143 | 1801 | 1799 | 272 | 271 | 27·93 | 27·87 |
| Atmosphere of train | 100 | | | 328933 | 173855 | 2180 | 1153 | 329 | 174 | 33·81 | 17·87 |
| Friction of train | | | | | 147392 | | 977 | | 147 | | 15·15 |
| Summary . . | 149·2 | 79·65 | 22·25 | 972886 | 934651 | 6450 | 6198 | 973† | 935 | 100 | 96·07‡ |

* The ratio of the orifice of the blast-pipe to the cylinder was $\frac{1}{474}$ in that case.

† By pressure 508·938 × 79·65 × 792·4 ÷ 33000 = 973·37 H. P. By Resistance 6450 × 4980·8 ÷ 33000 = 973·52 H. P.

‡ See pages 54 & 55.

The aggregate resistances overcome by the steam employed in locomotive engines, when submitted to the usual comparative units of power, appear to be enormous. The estimated powers of a man and of a horse have been shown in the explanation of the Tables. By making these the units of comparison with locomotives, an idea will be obtained of the value of such resistances.

The power of the 'Great Britain' locomotive, as given out during the 13th experiment in Table XI., at 61·3 miles per hour with a gross load of 149·5 tons, is equal to that of 796 horses, deducting the blast resistance; or including it, equal to 1018 horses; for $61{\cdot}3 \times 88 = 5394{\cdot}4$ feet per minute, and for resistance of train by Table XII. 100 tons $\times\ 23{\cdot}6 = 2360$ lbs.; and by Diagram of Resistances for engine and tender, $49\frac{1}{2}$ tons $\times\ 50{\cdot}68 = 2508{\cdot}66$: hence $\frac{2360 + 2508{\cdot}66 \times 5394{\cdot}4}{33000} = 796$ horse-power nearly. If to this we add 28 per cent. for back pressure, we have 1018 horse-power as the value of the resistances overcome by the steam in moving 149·5 tons at 61·3 miles per hour.

Taking only the tractive power of this engine as a guide, it may be interesting to estimate roughly the vast addition made to the resources of the nation by railways.

According to the Railway Journals there are about 4273 miles of railway opened, and making returns of traffic. As this mileage is regularly increasing, we may take 4300 miles as provided with locomotives, in the ratio of one engine to every two miles. Estimating their average power as only half that of the 'Great Britain,' we have 2150 locomotive engines usefully employed in the general service of the country. Their power will be $2150 \times 398 = 855{,}700$ horses' power. If we take Smeaton's estimate of the power which a man can continue to exercise as 3750 lbs. raised 1 foot in 1 minute, we have $\frac{2434{\cdot}33 \times 5394{\cdot}4 \times 2150}{3750} = 7{,}528{,}870$ men's power.

Since this estimate will be below rather than above the real engine power of railways in this country, it may be taken in round numbers as equal to 860,000 horses, or 7,600,000 men, added to the internal power and resources of Great Britain within the last eighteen years by railways. One leading and important feature in this vast accession of power is its portability,—being alike available for pleasure, for commerce, or for national defence.

Railways are therefore justly popular and truly powerful; and when the improvements of which they are susceptible have been carried out, their usefulness may be extended over a much wider field than at present, diffusing intelligence, promoting industry, and enhancing the value of the most secluded districts of the nation.

We learn with much pleasure that the British Association for the Advancement of Science has appointed the following Gentlemen to form a Committee, for the purpose of repeating experiments to determine the resistances of railway trains at the high velocities, under the altered circumstances of railways at the present time, viz. Mr. Hardman Earle, Mr. G. Rennie, Mr. E. Woods, Mr. W. Froude, Mr. J. Glynn, Mr. Wyndham Harding, and Mr. J. S. Russell. In this Paper we have attempted, from experimental data, to determine some of these resistances. There remain others without any assignable value as yet. It is therefore satisfactory to know that the subject in all its bearings will be fully investigated, with all the advantages of enlarged experience, powerful locomotives, and high velocities, under the sanction of the above distinguished Association.

# TABLE XIII.

*Table showing the Resistance caused by the Blast-pipe in lbs. and per cent. of the Total Pressure on the Piston at various Pressures and Velocities, as taken from the cylinder of the 'Great Britain' (broad-gauge) locomotive engine, by Indicator, during the Experiments made by Mr. D. Gooch for the Railway Commissioners. (See Table XI.) Also the Back Pressure, calculated by the Formula* $P^2 + V \times R \times {\cdot}00001$, *page* 58. *Driving wheels* 8 *feet diameter, cylinder* 18 *inches diameter and* 24 *inches stroke. Orifice of blast-pipe* 5 *inches diameter. Steam-ports* 13 × 2 = 26 *inches. Lead of slide-valves* ¼ *inch fall, fitted up with expansion gear. Exhaust-port* 13 × 3½ = 45½ *inches.*

| Experiments with Engine and Tender 50 Tons, Train 100 Tons = 150 Tons. | | | | | Experiments with Engine and Tender 50 Tons, Train 50 Tons = 100 Tons. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | From Indicator Cards. | | | By Formula. | | From Indicator Cards. | | | By Formula. |
| Velocity per hour. | Mean pressure on steam side of the piston. | Mean pressure on blast-pipe side of the piston. | Ratio per cent. of back pressure to total pressure on the piston. | Back pressure by formula. | Velocity per hour. | Mean pressure on steam side of the piston. | Mean pressure on blast-pipe side of the piston. | Ratio per cent. of back pressure to total pressure on the piston. | Back pressure by formula. |
| Miles. | lbs. | lbs. | Per cent. | lbs. | Miles. | lbs. | lbs. | Per cent. | lbs. |
| 13·1 | 19·1 | 2·27 | 11·88 | 1·7 | 19·8 | 19·31 | 1·31 | 6·78 | 2·02 |
| 19·4 | 25·7 | 1·9 | 7·39 | 2·89 | | 18·85 | 1·52 | 8·06 | 1·96 |
| | 24·95 | 2·38 | 9·53 | 2·78 | | 18·52 | 1·85 | 9·98 | 1·92 |
| | 23·91 | 2·45 | 10·24 | 2·62 | 21·8 | 30·2 | 3·79 | 12·55 | 3·78 |
| | 22·87 | 2·06 | 9· | 2·46 | | 26·75 | 3·75 | 14·02 | 3·17 |
| 19·8 | 19·75 | 1·91 | 9·67 | 2·07 | | 22·87 | 3·91 | 17·09 | 2·57 |
| | 25·39 | 2·06 | 8·11 | 2·86 | | 20·5 | 3·95 | 19·27 | 2·25 |
| | 24·27 | 1·54 | 6·34 | 2·69 | 24·7 | 19·37 | 1·58 | 8·15 | 2·24 |
| | 24·33 | 2·29 | 9·41 | 2·70 | | 18· | 1·5 | 8·33 | 2·08 |
| 19·8 | 24·58 | 4·33 | 17·63 | 2·74 | | 19·7 | 1·5 | 7·61 | 2·27 |
| | 24·33 | 4·5 | 18·5 | 2·70 | | 19·06 | 1·55 | 8·13 | 2·20 |
| 20·2 | 11·7 | 2·29* | 19·57 | 1·30 | 40·1 | 44·91 | 6·58 | 14·63 | 8·02 |
| | 25·29 | 1·79 | 7·07 | 2·88 | | 47·08 | 7·79 | 16·54 | 8·61 |
| | 24· | 1·95 | 8·12 | 2·67 | | 46·87 | 7·62 | 16·25 | 8·57 |
| 21·1 | 23·95 | 2·05 | 8·56 | 2·70 | 42·3 | 30·79 | 6·95 | 22·57 | 4·79 |
| | 23·85 | 2·39 | 10· | 2·68 | 43·9 | 30·27 | 4·63 | 15·3 | 4·76 |
| | 21·43 | 2·0 | 9·33 | 2·34 | | 31·83 | 5·05 | 15·86 | 5·06 |
| | 20·83 | 2·13 | 10·22 | 2·26 | | 29·62 | 4·33 | 14·61 | 4·64 |
| 44·1 | 57·72 | 10·3 | 17·84 | 12·28 | 44· | 34·18 | 5·61 | 16·41 | 5·55 |
| | 58· | 10·87 | 18·74 | 12·38 | | 27·41 | 5·37 | 19·59 | 4·52 |
| | 59· | 10·72 | 18·17 | 12·74 | | 28·25 | 5·14 | 18·19 | 4·39 |
| | 60·2 | 10·82 | 17·97 | 13·18 | 51·2 | 43·19 | 9·71 | 22·48 | 8·03 |
| 45·3 | 55·16 | 15·20 | 27·59 | 11·43 | 58· | 49·6 | 11·56 | 23·3 | 10·17 |
| | 47·66 | 24·37* | 51·13 | 9·03 | | 52·22 | 12·29 | 23·53 | 11· |
| 45·6 | 58·85 | 11·37 | 19·32 | 12·75 | 59·2 | 58·85 | 18·37 | 31·21 | 13·34 |
| | 57·27 | 11·87 | 20·72 | 12·18 | | 59·41 | 14·74 | 24·81 | 13·53 |
| | 34·77 | 5·87* | 16·88 | 5·74 | | 63·14 | 17·18 | 27·2 | 14·97 |
| 56·6 | 79·4 | 22·5 | 28·33 | 22·08 | | 66·20 | 18·7 | 28·25 | 16·2 |
| | 80·6 | 21·9 | 27·17 | 22·66 | | 65·08 | 18·95 | 29·11 | 15·75 |
| | 81·1 | 21·6 | 26·63 | 22·92 | 62·4 | 40·62 | 11·45 | 28·18 | 7·84 |
| | 77·52 | 23· | 29·67 | 21·15 | | 37·68 | 8·87 | 23·54 | 7·32 |
| 57·4 | 60·87 | 14·81 | 24·33 | 14·02 | | 38·62 | 8·52 | 22·06 | 7·35 |
| | 57·93 | 14·45 | 24·94 | 12·93 | | | | | |
| | 58·09 | 12·47 | 21·47 | 13· | | | | | |
| | 54·95 | 14·54 | 26·46 | 11·89 | | | | | |

* Priming or slipping when card was taken.

**Note.—A more condensed Table of the mean resistances for each velocity would have given fair averages with fewer variations than by giving them all separately. As, however, they were taken under all the changing circumstances from calm to stormy weather—from velocities of 13 to 62 miles an hour—slipping—when priming was observed, and probably also when it was with other contingencies not observed, they form a valuable record of the practical variations taking place in a locomotive cylinder. It will be observed that, as a whole, they follow nearly the general law of the formula.**

# GLOSSARY OF TERMS USED IN DESCRIBING A LOCOMOTIVE ENGINE AND TENDER.

*Adhesion*—as applied to locomotives, is the pressure or bite of the wheels upon the rails by which heavy loads are drawn along two smooth iron bars. When the engine is in motion, the pressure on the rails is not alike at all points of the circumference of the driving wheel, but to what extent this inequality exists at high velocities has not been ascertained.

*Ash-pan.*—An iron box, open to the front only, attached to the fire-box to receive the ashes from the fire.

*Axle.*—The iron shaft on which two wheels are fixed, and named according to its position.

*Axle bearing.*—The gun-metal, or other metal bearing, under which the axle journal revolves. It is nicely fitted to the journal, and lubricated by a syphon, to reduce, as far as practicable, the friction on the journal.

*Axle-box.*—The box (usually cast iron) fitted up with a metal bearing in it, which rests upon the polished part of the axle.

*Axle-box cover.*—The plate of iron (usually lined with leather) fitted to the top of the axle-box to keep the oil clean, and also from shaking out by the motion of the engine.

*Axle-box syphon.*—The small tubes fitted into the top of the axle-box for feeding oil on to the axle journal as it revolves. The oil is fed by a piece of cotton or worsted, having one end introduced into these pipes, and the other end lying down amongst the oil in the axle-box.

*Axle: driving wheel.*—With inside cylinders, this is a cranked axle. With outside cylinders, it is a straight axle. It is called the driving axle because the connecting-rods and eccentric-rods connect this axle to the pistons, slide-valves, and pumps, and by converting the rectilinear motion of the piston into a rotary one, it propels or drives the engine in the direction required.

*Axle-guards*, or *horn-plates.*—The parts of the frame in which the axle-box slides up and down, as acted upon by the springs.

*Axle-guard stays.*—The iron rods bolted to the frame and to all the ends of the axle-guards, to strengthen them.

*Axle: journal* or *neck.*—The part of the axle turned and polished for revolving in the axle-box bearing.

*Axle, leading.*—The front axle of the engine. Eight-wheeled engines have two axles in front of the driving wheel axle, and they are occasionally called leading axles.

*Axle, trailing.*—The last axle of the engine, usually placed under the foot-plate. In Stephenson's and Crampton's patent engines, the driving wheel axle is the last axle of these engines.

*Balance weights.*—Weights used to counterbalance the piston, quadrants, cranks, or connecting-rods. The piston balance moves between parallel guides; that for the quadrants is suspended from a lever below the boiler, and the one for the crank and connecting-rod is fixed to the rim of the driving wheel. A proper system of balancing the working parts is very important.

*Ball and socket-pipes.*—The brass pipes used on some engines to convey the water from the tender to the boiler, or steam from the boiler to heat the water in the tender.

*Ball-valve.*—The spherical part of the pump-valve or clack. In working, this ball is forced up, to admit the water to the pump and to the boiler, and falls into its seat immediately the stroke of the pump-ram is completed, to prevent the escape of steam from the boiler, or water from the pump to the tender again.

*Blast-pipe.*—The pipe fixed over the exhaust-ports of the cylinders, with the top open into the centre of the chimney, through which the steam escapes into the atmosphere, after having performed its duty. The draft or blast on the fire is regulated by increasing the size of the top of the blast-pipe for a milder draft, and by lessening it for a stronger draft. It is the part which blows the fire, and as at present arranged requires from $\frac{1}{16}$ to $\frac{3}{11}$ of the whole power of the steam on the piston to do so.

*Blow-off cocks.*—Cocks attached to the lowest part of the boiler, to be opened when the boiler becomes foul, that the steam may, as far as practicable, drive the deposit from the water to those parts where it can be got out.

*Boiler.*—The fountain head or source of all the power of an engine. Externally it consists of a large tube-like centre piece, attached to a square or semicircular fire-box at one end, and to a square smoke-box at the front end, over which is placed the chimney. Internally it is filled for about two-thirds of its area with small tubes of brass or iron, through which tubes the heated air and gases pass from the fire to the chimney. The fire-box (usually made of strong copper) is fixed by copper or iron stays about three inches clear of the outside shell of the boiler all round. Both tubes and fire-box are surrounded with water, whereby steam is generated with great rapidity. The heating area of locomotive boilers varies from about 400 to about 2000 square feet. The power of the engine is determined by the capabilities of the boiler to generate steam; for no matter what size the cylinders are, if they are not filled with steam of the proper temperature the actual power will be less than the nominal power: hence the importance of good boilers.

*Brake.*—The combination of levers, rods and screws whereby blocks of wood, rope, or other material, are brought forcibly in contact with the wheels of the tender to stop the engine or train, by simply turning a handle placed conveniently for the purpose.

*Brake angle plates.*—The strong angle plates bolted to the brake-rod of the tender, on one side, and on which the brake-block is screwed on the other side.

*Brake-blocks.*—The piece of wood or rope fixed to the angle plate to be pressed up against the wheel, when required, to stop the engine. In dry weather these blocks sometimes ignite, and thus raise a smoke which can be readily felt by the passengers in the train.

*Brake levers.*—The projecting arm or rod from the shaft on which the nut of the brake-screw is fixed.

*Brake pinion.*—The segmental toothed wheel placed on the lever shaft to work between the rack ends of the brake-rods, which thus brings the blocks in contact with both sides of the wheels at the same time.

*Brake-rods.*—The moveable rods or bars of iron placed along the side of the tender, worked by the pinion, and to which rods the angle plates are attached.

*Brake-screw.*—The screw to which is fixed the handle used in working the brake.

*Buffer-bar.*—The strong front bar of the frame on which the leather buffers are fixed.

*Buffer-rod.*—The strong iron rod with a broad head, on which is fixed a circular piece of wood. The other end impinges against a strong spring, to soften the concussion of carriages striking the tender.

*Buffer-springs.*—The springs used for buffing against, and also in some cases for drawing by. Strong flat steel springs, reaching all the width between the buffers, Vulcanized India-rubber circular rings, and spiral steel springs, are all used for buffing against, according to the opinion of the maker or designer of railway carriages.

*Buffers, Leather.*—Leather cases, hooped with iron and filled with horse-hair, coir, or other elastic material, used in front of engines, and sometimes on tenders and carriages, instead of springs.

*Chimney.*—The chimney is regulated in size for each engine so as to act in union with the blast-pipe, to produce a proper blast on the fire. This is done by each exhaust of steam from the cylinder creating a partial vacuum in the chimney: hence a rush of air takes place through the fire and tubes to fill this vacuum, and these successive rushes of air 'blow the fire.' This vacuum ranges from 5 to 10 inches of a water-gauge,—the mild blast producing least vacuum and least consumption of fuel.

*Cinder frame.*—A wire-work frame, placed in front of the tubes to arrest the ascent of large pieces of ignited coke.

*Clack.*—The complete valve of the pump, where the ball-valve is enclosed in a frame or cage, to limit its rise, and guide its fall into the steam-tight seat of the orifice of the pipe.

*Clack-box.*—The box fitted on to the boiler, where a ball-clack is placed to close the orifice of the feed-pipe, and prevent steam or hot water reaching the pumps. The ball of the clack is raised from its seat by the stroke of the pump-plunger forcing the water against it, and which water then passes into the boiler, while the instant fall of the ball prevents egress from the boiler.

*Clack seats.*—Two recesses in each pump, for the clacks to fit into.

*Cleading.*—Usually made of narrow strips of timber, neatly fitted round the boiler and fire-box, to prevent the radiation of the heat. Externally, this is sometimes covered with zinc. Beneath, a coating of dry hair felt is placed between the boiler and timber, the better to prevent the radiation of the heat.

*Connecting-rod bearings.*—The gun-metal or composition metal bearings fitted into the straps to suit the particular part they are to work on.

*Connecting-rod straps.*—Strong pieces of iron bent like the letter ⊏, which fit the ends of the connecting-rod, and into which the axle bearing is fitted in two parts. They are attached to their respective ends of the rod by keys and cotters, which are taken out, and the half of the bearing also, when a connecting-rod has to be put on. The strap and half-bearing are then brought over the axle or cross-head, the other half-bearing put into the strap, the end of the rod brought up against the bearing, and secured by the keys and cotters. The method of taking off a rod is of course the reverse of putting one on.

*Connecting-rods.*—The strong iron rods which connect the pistons to the driving wheel axle, and thus give motion to all the machinery.

*Connecting-rods, outside* or *side rods.*—The rods which connect together the wheels of goods engines. They are seen outside the wheels, making an irregular forward motion, like watermen rowing a boat. By connecting the wheels together, one pair cannot slip without the others, and the greatest practicable adhesion is thus obtained.

*Cross-head blocks.*—The parts which slide between the parallel guides. The ends of the cross-head are fitted into these blocks. The cross-head, cross-head guides, and block, constitute what is called 'the motion of the engine.'

*Cross-head guides.*—The parallel bars between which the cross-head moves in a right line with the cylinder and driving wheel axle. They are also called *motion bars.*

*Cross-heads.*—The part of the motion into which the piston-rod is fitted on the cylinder side and the connecting-rod attached on the driving wheel axle side.

*Cylinder-cocks.*—Cocks placed in convenient parts of the cylinder for admitting oil to lubricate the piston, or by which to blow out the condensed steam, or other deposit in the cylinders.

*Cylinder cover.*—The ends of the cylinder, made to take off and put on at pleasure.

*Cylinders.*—Usually made of cast iron, and bored out accurately, into which the piston is fitted steam-tight, yet easily moveable by the pressure of the steam. An oblong opening at each end alternately admits steam to the cylinder from the boiler, and from the cylinder to the atmosphere. It is therefore an important part, as it regulates the power of the engine.

*Dampers.*—An iron Venetian blind, fixed to the smoke-box end of the boiler, in front of the tubes. It is shut down when the engine is standing, and thus stops the draft and economizes fuel, but it is opened when the engine is running.

*Dome.*—The conical part of the boiler, forming a steam chamber, and terminating the top of the fire-box part. The safety-valves are usually placed on the top of the dome or the body of the boiler.

*Dome cover.*—The brass or copper cover which encloses the dome, to prevent the radiation of heat.

*Drag-bar.*—A strong iron rod with eye-holes at each end, connecting the engine and tender by means of the drag-bolt and spring.

*Drag-bolt.*—The strong bolt coupling the drag-bar of the tender and engine together, removeable at pleasure.

*Drag-hook and chain.*—The strong chain and hook attached to the front of the engine buffer-bar, to connect it on to any other engine or tender: also attached to goods waggons drag-bars.

*Drag-spring.*—A strong spring placed near the back of the tender. It is attached by the ends to the drag-bar which connects the engine and tender, and by the centre to the drag-bar which connects the train to the tender.

*Eccentric hoops.*—Hoops fitted round the projecting part of the eccentric sheaves to strengthen them.

*Eccentric-rod and strap.*—The rod, the strap end of which encircles the eccentric sheave, and the other end connects it with the quadrant, or rocking shaft, according to the class of engine. In some engines the end is forked to go on the stud of the rocking shaft, and opens out something like the letter V: or when only one rod is used for both back and forward movements, it resembles the letter X. In other engines it is attached to the quadrants by a bolt, one rod for forward gear, and another rod for backward gear.

*Eccentrics.*—Circular sheaves with a hole for the driving wheel axle, about 2 inches out of the centre of the sheave, which thus makes it project some 4 inches more from the centre of the driving axle on one side than on the other. It is this eccentricity of motion which works the slide-valve gear and pumps in a very satisfactory manner. Eccentrics are fitted in two parts, and secured to the axle by a hoop and set-bolts.

*Feed-pipes.*—The copper pipes reaching from the clack-box to the pump, and from the pump to the tender, to convey water to the boiler.

*Feed-pipe cocks.*—The cocks to regulate the supply of water to the boiler, the handle of which is placed conveniently to open and shut at pleasure.

*Feed-pipe strainer,* or *strum.*—A perforated half-spherical piece of sheet iron, after the manner of the rose end of a watering pot: it is placed over the open end of the feed-pipe in the tender tank, to protect it.

*Fire-bars.*—Wedge-shaped iron bars, fitted to the fire-box with the thick side uppermost, to support the fire. The ends rest on a frame.

*Fire-bar frame.*—A frame made to fit the fire-box on which the fire-bars rest. A plan of dropping all the bars at once by a moveable frame, acted on by a lever and handle outside the fire-box, has been frequently tried, but the action of the intense heat soon puts it out of working order.

*Fire-box.*—The box (usually made of copper) in which the fire is placed. The outside shell, as already explained, is of iron, separated from the copper fire-box by a space of about 3 inches all round for water. (See *Boiler.*)

*Fire-box door.*—The door opening into the fire-box, facing the tender, by which coke is supplied to the fire.

*Fire-box partition.*—In large fire-boxes a division is made in the box, into which water is admitted: this division is about the height of the fire-box door, and divides the fire into two parts, thereby increasing the heating surface of the fire-box.

*Fire-box stays.*—Deep strong iron stays, bolted to the top of the copper fire-box, to enable it to resist the pressure of the steam. Round copper or iron stays are also used to connect the outside shell to the inside box, in the proportion of about one stay to every 4 square inches of flat surface.

*Foot-plate.*—The platform on which the engine-man and fire-man attend to their duties.

*Frame.*—The strong frame-work outside the wheels which supports the boiler and machinery on the axles.

*Frame, Inside.*—Some engines have the supporting frames within the wheels, and are called ***inside framed engines***. Besides this frame, resting on the axles, there are also other strong stays from the fire-box to the smoke-box, called ***inside framing*** or ***stays***, for supporting the works and strengthening the boiler.

*Gauge-cocks.*—Three cocks attached to the boiler, by which to ascertain the height of the water and steam, when required.

*Gauge glass.*—A strong glass tube, also connected with the boiler by two cocks attached to the gauge-cock pedestal. The water is admitted to this tube by the lowest cock, the steam by the top cock. It thus becomes an index to what is going on inside the boiler, exhibiting the height or agitation of the water in it. A small cock is placed below the glass for blowing out any sediment which may be deposited in it.

*Gauge lamps.*—A small lamp placed beside the gauge glass at night, that the state of the water in the boiler may be seen by the engine-man.

*Hand gear.*—The handles of the working gear, placed conveniently to the foot-plate, so as all to be within reach of the engine-man when he requires to use them for regulating the different parts of the engine.

*Hand-pump.*—The pump placed by the side of the fire-box, to be worked by a hand lever when the engine has to stand with steam up.

*Hand-railing.*—The railing along the sides of the engine, to protect persons passing to the front of the engine for any necessary purpose.

*Horn-plates.*—See *Axle-guards.*

*Hose-pipes.*—Elastic pipes made of canvass, saturated with a solution of India rubber, or of galvanized India rubber, forming a good elastic connection between the engine and tender feed-pipes. They are now generally used in preference to ball and socket connections for conveying the steam to the tender.

*Links.*—Round or flat pieces of iron with round holes at each end. They are used to connect together (by bolts) different parts of the mechanism of the engine.

*Man-hole.*—A hole in the boiler, placed conveniently for a man to get inside, when required, and protected by a steam-tight cover.

*Man-hole cover.*—A strong plate of iron, bolted over the man-hole so as to be removeable when required.

*Motion.*—The cross-head, cross-head guides, and blocks, taken as a whole, are called the ***motion***. (See the description of these parts separately.)

*Mud plugs.*—Tapered screw-plugs, fitted into convenient parts of the boiler, to admit of its being washed out by these plug-holes when necessary.

*Pet-cocks.*—Small cocks attached to the pumps to relieve them from any steam or hot water which might escape from the boiler through an imperfect top clack. When opened, these cocks also indicate how the pumps are working, by throwing out forcibly a jet of water when they are in good order.

*Piston.*—A circular metallic body, flat at both ends, made a little smaller than the cylinder. It is fitted up with elastic rings, which fit the cylinder steam-tight, and are readily moveable by the steam. When steam is admitted to the cylinder it presses against the flat end of the piston, and thus moves it to the end of the stroke limited by the crank. Before quite reaching the end of the stroke, the piston is met by steam admitted on the opposite side, to be ready to force it back to the other end of the cylinder again, where a similar procedure takes place. This alternate action of the piston is by the crank and connecting-rod converted into a rotary motion, to be used for driving machinery, or a locomotive along a railway, as it may be required.

*Piston cover.*—The end plate which confines the rings of the piston so that the whole may be steam-tight, yet the rings easily moveable to press against the cylinder. The cover is fixed on by tap-bolts, and is taken off to adjust the pressure of the rings as may be required.

*Piston rings* or *packing.*—These are of various descriptions, according to the opinions of different engineers. Usually they consist of two metallic eccentric rings, turned and ground steam-tight to each other, and also to fit the cylinder steam-tight. They are cut open at the thinnest side, and expanded by a steel spring and wedge-piece applied to the opening, so as to fit the cylinder. They form the elastic portion of the piston in whatever form they are made.

*Piston-rod.*—The steel or iron rod firmly attached to the piston, and connecting it with the cross-head through a steam-tight stuffing-box.

*Piston springs.*—Steel springs, usually fitted round inside the piston rings, having a set-screw and wedge-piece fitted to the opening of the ring, to adjust the pressure against the cylinder. These springs also vary in form to suit the different descriptions of piston rings.

*Pressure.*—The elastic force of the steam, generally expressed in lbs. per square inch.

*Pump-plunger* or *ram.*—The metallic rod which works the pump through a stuffing-box. It is sometimes attached to the cross-head, at other times worked from an eccentric on the driving axle. The latter is considered the best mode. In Mr. Crampton's engine it is worked from the piston.

*Pumps.*—Force-pumps of the usual description, with two valves or ball-clacks fitted to each pump, and a stop-valve or clack attached to the boiler. They are fitted with air-tight plungers, which by one stroke create a partial vacuum in the pumps, and by the returning stroke force forwards to the boiler the water from the tender which had filled this vacuum by the pressure of the atmosphere.

*Quadrant,* or *expansion gear.*—The quadrant is the principal link of the expansive slide-valve motion. It is a double-sided link, suspended from the boiler, with a metal block fitted to the inside of the quadrant link, and attached to the slide-valve rod. The reversing gear is connected with this block, which, on being raised to the top of the quadrant, sets the slide-valve in motion in one direction; but on the block being lowered to the bottom of the quadrant, the slide-valve is reversed, and opens the opposite steam-port. The expansion gear is regulated between these extremes. This is done by so arranging the levers and rods that the lead of the slide-valve is preserved through every variation of the expansion gear. The travel of the slide is, however, reduced by each variation, and thus cuts off the steam from the cylinder more and more, according to the adjustment of the expansion gear. The steam in the cylinder thus cut off at two-thirds or three-fourths, or any other proportion of the stroke, expands to the end of the stroke, and the mechanism which accomplishes this desirable purpose is called the *expansion gear.*

*Quadrant block.*—The metal block connected to the slide-valve rod, which is moved up and down inside the quadrant link by the reversing and expanding gear. The quadrant link, quadrant block, levers, guides, and hand gear connected with them, are, as a whole, called the *expansion gear.*

*Rail* or *life-guards.*—Strong iron rods reaching down within about 2 inches of the rails, to catch and throw to one side any opposing article which may be on the rails.

*Regulator.*—A steam-tight valve, placed on the steam-pipe to regulate the admission of steam to the steam chest.

*Regulator-cock.*—A cock placed to admit oil or tallow to lubricate the faces of the regulator.

*Regulator cover.*—The outside cover, removeable when required to examine the regulator.

*Regulator handle and rod.*—The handle and rod by which to open and shut the regulator at pleasure.

*Regulator shaft and levers.*—The shaft and levers placed in front of the smoke-box when each cylinder has a separate regulator. A rod connected with the shaft leads to the foot-plate, where a handle is placed conveniently for use.

*Reversing handle and guide.*—The handle placed beside the foot-plate conveniently for use when required. The guide is a quadrant fixed to the foot-plate, notched for a catch of the reversing handle for each variation of the expansion gear. To reverse the engine, the handle is removed to any notch past the centre of the guide on the opposite side in which it was before. Expansion is varied by moving the handle from one notch to another notch on the same side of the centre of the guide from which the engine is working. When the handle is on the centre notch, the engine is said to be *out of gear*.

*Reversing shaft.*—The shaft, with levers on it, connected with the eccentric-rods in the rocking shaft class, but with the slide-valve rod in the expansion gear class of engines. Both arrangements effect the object of moving the slide-valve so as to admit steam to the contrary side of the piston to which it had previously been admitted, and thus reverse its motion, and with it the motion of the engine also.

*Rocking shaft.*—The shaft, with levers on it, which works the slide-valve in some engines. The eccentric-rod drops on to a stud fixed in one lever, and the links of the slide-valve rod are attached to the opposite lever on the same shaft. This mode of working the slide-valve was generally adopted before the introduction of the direct-action mode of working them by Mr. Stephenson.

*Safety-plug.*—A bolt having the centre filled with a fusible metal. It is screwed into the top of the fire-box, that the metal may melt out by the increased temperature when the water becomes too low, and thus admit the water to put the fire out, and save the tubes and fire-box. When the water is allowed to fall below a proper height, there is great risk of spoiling both the fire-box and tubes by the intense action of the fire. This is called 'burning them;' and tubes subjected to such a trial are unfit for use again, as the strength of the metal has been destroyed.

*Safety-valve lever.*—The lever fixed at one end to a stud, and resting on the valve at a short distance from this stud. Its length is proportioned to the area of the valve, so that the spring balance may indicate accurately the pressure in lbs. per square inch on the boiler above the atmosphere.

*Safety-valves.*—Two valves placed on the boiler for the escape of steam when it exceeds the pressure limited by the load on these valves. One of them is placed beyond the control of the engine-man, and is usually called the *lock-up valve*. The other is regulated by a lever and spring balance, at a little lower pressure than the lock-up valve.

*Sand-boxes.*—Boxes filled with sand, usually placed near the driving wheels, with a pipe to guide the sand to the rails, to be used when slipping takes place.

*Setting the slide-valve.*—The eccentric is brought as much before the crank as to give the required lead to the slide-valve when the crank is on the centre, that is, in a straight line with the cylinder. The handle is then moved to each separate notch, and the position of the slide and piston carefully taken for each variation. These are then recorded in the following manner:

____________________ *Engine,* ____________________ 184 .

| | | | |
|---|---|---|---|
| | Inches. | | Inches. |
| Diameter of cylinders . . . . . . | 18 | Outside lap of valve . . . . . . | 1 |
| Length of stroke . . . . . . . | 24 | Inside lap of valve . . . . . . . | $\frac{1}{32}$ |
| Size of steam-port . . . . . . . | 13 × 2 | Size of exhaust-port . . . . . . | 13 × $3\frac{1}{2}$ |

| No. of notch in reversing handle guide. | Travel of slide-valve. | Lead of slide-valve. | Steam cut off. | | Exhaust opens. | | Compression begins. | | Steam-port opens. | | Diameter of blast-pipe. | REMARKS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Front stroke of piston. | Back stroke of piston. | Front stroke of piston. | Back stroke of piston. | Front stroke of piston. | Back stroke of piston. | Front stroke of piston. | Back stroke of piston. | | |
| | inches. | inches. | inches. | inches. | inches. | inches. | inches. | inches. | inches. | inches. | inches. | |
| 1 | $5\frac{1}{8}$ | $\frac{11}{32}$ | $19\frac{7}{8}$ | 19 | $22\frac{3}{4}$ | $22\frac{3}{8}$ | $22\frac{1}{2}$ | $22\frac{3}{16}$ | $1\frac{1}{2}$ | $1\frac{3}{4}$ | $5\frac{1}{8}$ | |
| 2 | $4\frac{1}{2}$ | $\frac{11}{32}$ | $18\frac{9}{16}$ | 18 | $22\frac{3}{16}$ | $21\frac{7}{8}$ | 22 | $21\frac{5}{8}$ | $1\frac{3}{16}$ | $1\frac{3}{8}$ | ,, | |
| · 3 | 4 | $\frac{11}{32}$ | $16\frac{5}{8}$ | $16\frac{5}{16}$ | $21\frac{3}{8}$ | $21\frac{1}{8}$ | $21\frac{1}{4}$ | 21 | $\frac{15}{16}$ | $1\frac{1}{16}$ | ,, | |
| 4 | $3\frac{1}{2}$ | $\frac{11}{32}$ | $13\frac{5}{8}$ | $13\frac{5}{8}$ | $20\frac{5}{16}$ | $19\frac{13}{16}$ | 20 | $19\frac{1}{8}$ | $\frac{11}{16}$ | $\frac{13}{16}$ | ,, | |
| 5 | $3\frac{1}{8}$ | $\frac{11}{32}$ | $9\frac{1}{2}$ | 10 | $18\frac{7}{16}$ | $18\frac{1}{16}$ | 18 | $17\frac{9}{16}$ | $\frac{9}{16}$ | $\frac{9}{16}$ | ,, | |
| 6 | $2\frac{11}{16}$ | $\frac{11}{32}$ | $5\frac{7}{16}$ | 6 | $15\frac{5}{8}$ | 15 | $15\frac{1}{4}$ | $15\frac{1}{4}$ | $\frac{11}{32}$ | $\frac{11}{32}$ | ,, | Centre notch. |

The above measurements are carefully taken and registered by the mechanic who sets the slide-valves, on a form supplied to him for that purpose. This register is then entered in a book kept by the superintendent, that he may know the state of the slides of any of the engines when they left the shop.

*Side chains.*—Chains and hooks, fixed to the sides of the tender and engine for safety, should the central drag-bar give way.

*Signal lamps.*—Large lamps used for signals at night, or in fogs. Some lamps have a recess between the burner and lens for dropping in any particular coloured glass, according to the light which is to be shown, with other recesses for the extra glasses. In other lamps, as made by Mr. Cutts, of Sheffield, a glazed cylinder is turned round to change the colour of the light.

*Slide-valve.*—The valve placed in the steam chest to work over the steam-ports. It regulates the admission of steam to the cylinder from the boiler, and the escape of the steam from the cylinder to the atmosphere. Its form is that of an arch in the centre, with a flat face all round to keep it steam-tight on the face of the steam-ports. It is by the arched part that the steam escapes to the atmosphere. It is a simple valve, with two draw-backs; namely, that at high velocities it cuts off the escaping steam too soon; and that the pressure of the steam upon it is unbalanced. Numerous attempts have been made to obviate these defects, some of which it is hoped will be successful. The 'Iron Duke' works with balance pistons for the slide-valves.

*Slide-valve lap, Outside.*—The portion of the valve which would overlap the steam-ports when placed over them. For instance, if the steam-ports measure 8 inches over all the ports, and the valve be 10 inches broad, this would be an overlap of 1 inch on each side of the ports, and is called the 'lap' of the valve. Expansion was formerly regulated by the extent of lap only, but it is now regulated by both the lap and the expansion gear, which give greater scope in doing so. *Inside lap* is the portion of the valve face which would overlap the inside of the steam-ports when placed over them; for if the steam-ports were 4 inches from inside of the one port to the inside of the other port, and if the arched part of the valve only measured $3\frac{7}{8}$ inches across, this would give $\frac{1}{16}$ of an inch lap on each side, which is called *inside lap.*

*Slide-valve lead.*—The width which the steam-port is opened by the slide-valve when the piston is at the end of the stroke. It varies from ⅛ to ½ inch, according to the work required of the engine. The lead is obtained by fixing the eccentric on the axle, a little in front of the crank, by which arrangement the steam-port is opened in front of the direction in which the piston is moving before the latter has completed its stroke. By these means the steam-port is thrown quickly open when the piston commences its return stroke, and has at once the full pressure of the steam against it.

*Slide-valve rod and frame.*—The frame is fitted on to the top part of the valve, and the rod connects the frame with the slide block, or rocking shaft, according to the description of valve gear of the particular engine.

*Slide-valve rod guide.*—A bracket fixed to the boiler, the lower end of which is fitted for the slide-valve rod to work through. A set-screw is useful in this guide, for fixing the rod when the valve has to be disconnected.

*Slide-valve motion.*—A short motion similar to the piston-rod motion, connecting the quadrant to the slide-valve by parallel guides.

*Slide-valve travel.*—The distance which the slide-valve travels in one direction, for each stroke of the piston. This is from 4 to 5¼ inches generally, but is reduced by each variation of the expansion gear, and its travel is taken for both the front and back strokes of the piston for each notch where the handle is fixed. The up and down quarter-revolutions of the crank do not equally draw the piston the half length of the cylinder, and with the expansion gear they so far affect the working of the slide-valve that it is necessary to take the front and back stroke action separately.

*Smoke-box.*—The end of the boiler on which the chimney is placed. Engines with inside cylinders have them placed in this box, which keeps both them and the steam-pipes at a high temperature.

*Smoke-box door.*—The door in front of the smoke-box, by which access is gained to the cylinders, tubes, blast-pipe, steam-pipes, and other parts placed in this box.

*Splashers.*—The cover or guard placed over the wheels (usually faced with brass), to prevent any person on the engine coming in contact with the wheels, and also to protect the machinery from any wet or dirt thrown up by them from the rails or sleepers.

*Split-pins and cotters.*—Round and flat pins, with a head at one end, and split at the other end. They are used through the ends of bolts, to keep them from getting out of their place, the split end being opened like the letter ≺, to keep the pin or cotter from falling out.

*Spring balance.*—A spiral spring weighing machine, fixed to a stud, at one end, and at the top end to the safety-valve lever by a screw, used to regulate the pressure on the boiler by the index of lbs. on the balance.

*Spring hooks.*—The hooks fixing the driving wheel spring to the frame. A screw on the end of the hook is used to regulate the weight on the driving wheels.

*Spring pins.*—Iron rods fitted between the springs and the axle-boxes, to sustain and regulate the pressure on the axles.

*Springs.*—Those attached to the frame support the engine and tender upon the axles, and are named after the different parts they apply to; as leading springs for the leading axle; driving springs for the driving axle; trailing springs for the trailing axle; tender springs, &c. There are others, such as drag springs, buffer springs, &c., all proportioned in strength to the particular duty they have to perform.

*Stays, Outside.*—Strong stays, binding the boiler and frame together.

*Stays, Inside Boiler.*—Rods of iron, binding together the flat ends of the boiler. The flat sides of the dome are likewise strongly bound together by iron rods. Without these stays they could not resist the pressure of the steam against so large a surface.

*Stays, Inside frame.*—Strong stays placed below the boiler, firmly fixed at one end to the fire-box and at the other end to the smoke-box. They support the inside bearings of the driving axle and other parts of the machinery.

*Stay wedges.*—Wedges fitted to the inside bearings of the driving axles, to keep them in their proper position in the stays.

*Steam chest.*—A box attached to the cylinders, into which the steam is admitted by the regulator. The slide-valve works in this box over the steam-ports, which open into this box from the cylinder.

*Steam chest cocks.*—Oil cups, placed conveniently for lubricating the faces of the steam-ports and slide-valve.

*Steam compression.*—The steam which had performed its duty in the cylinder, but had not escaped before the slide-valve closed the exhaust-port, is then compressed by the advancing piston. This compression begins, according to the lap and travel of the slide, from 2 to 6 inches from the end of the stroke, and increases the back pressure. It is, however, of advantage in checking the momentum of the piston and relieving the strain on the connecting and piston-rods at the end of each stroke, and is not therefore all lost power.

*Steam exhaust-port.*—The passage opened below the slide-valve from the cylinder to the atmosphere. It is placed between the two steam-ports, and is nearly twice their area, the more freely to permit the escape of the steam. It is open to the blast-pipe, and is cut off from all communication with the steam in the steam chest by the slide-valve. The arched part of the slide-valve opens the passage from the cylinder into the central exhaust-port, where, through the blast-pipe and chimney, it escapes to the atmosphere, and by this means produces the draft on the fire, as previously explained.

*Steam indicator.*—A small cylinder with a piston of 1 inch area, attached to a well-adjusted spring. The indicator cylinder is supplied with steam from the working cylinder, and a pencil connected with the spring registers on a roll of paper which passes under it the pressure of the steam in the working cylinder. An indicator or steam card is the registry of the pressure on the steam side, and also on the blast-pipe side, for the return stroke of the piston.

*Steam-pipe.*—The pipe which collects and conveys the steam to the steam chest. It begins inside the boiler. In boilers with domes, the receiving pipe is raised as high as possible, and turned back round the edges of the open end, to prevent any water which might rise so high from entering the pipe. In boilers having no domes, the steam is collected in a horizontal pipe pierced with numerous small holes. After being collected, the steam-pipe is continued outside the boiler to the steam chest.

*Steam-pipe for tender.*—A small pipe attached to the boiler by a cock, for admitting the spare steam to heat the water in the tender.

*Steam-ports.*—Two passages from the steam chest to the cylinder. The steam is admitted to and from these passages by the slide-valve opening the port for the admission of steam to the cylinder, and then, by its covering this port from the steam in the steam chest, it opens the same passage through the arched part of the slide-valve into the central exhaust-port. The steam thus escapes from the cylinder by the same port by which it entered being opened to the atmosphere.

*Stuffing-boxes* or *glands.*—Boxes with recesses in them for admitting some elastic metallic or hempen material, to render steam-tight any rod working through this stuffing or packing. The piston-rods, slide-valve rods, regulator-rods, and pump-plunger, all work through stuffing-boxes of this description.

*Syphon cups.*—Cups placed for feeding oil to the working parts of the machinery, trimmed with cotton or worsted, the same as the axle-boxes.

*Tank.*—The part of the tender which contains the water, varying, according to the engine it is attached to, from about 500 to 1600 gallons in capacity.

*Tires.*—The outside hoop round the wheels, generally with a flange to keep and guide them on the rails. Mr. Stephenson's patent engine and eight-wheeled engines are usually made without flanges on the tires of the driving or centre wheels. Some tires are steeled on the part subjected to most wear, which makes them last much longer than iron tires.

*Tube ferrules.*—Thin slightly tapered hoops, one of which is driven in at each end of each tube, to fix it securely in the boiler. Formerly they were made of steel or iron; now cast iron ferrules are found to answer very well.

*Tube plug-ram.*—A long rod with a socket end, into which the tube plug fits, and the plug is thus driven into the burst tube, and the plug-ram withdrawn.

*Tube plugs.*—Tapered iron or wooden plugs, used for driving into the end of a burst tube.

*Tubes.*—Thin brass or iron tubes, about 2 inches outside diameter. They are the length of the boiler, and fixed in it by a ferrule driven in at each end, which makes them steam-tight. They are surrounded with water externally, and internally open to the atmosphere by the chimney. The heated gases and smoke from the fire pass through them, and they are thus the means of rapidly generating steam. The number of tubes in boilers varies from 60 or 70 up to above 300, according to the power of the engine and width of the fire-box.

*Union screws* or *joints.*—The brass unions for connecting the elastic hose-pipe of the tender to the feed-pipe of the engine. Smaller ones also connect the tender steam-pipe with the feed-pipe and with the boiler. The feed-pipe is likewise attached to the lower end of the pump by a large union screw.

*Wheels.*—An ancient and well-known invention for obtaining a rolling progressive motion. They receive names corresponding to the part of the engine or tender they support; as leading, driving, trailing, &c. Driving wheels vary in size from 4 feet 6 inches up to 10 feet diameter. Leading and trailing wheels vary from 3 feet up to 4 feet 6 inches diameter. Tender wheels are usually about the same size as the leading and trailing wheels of the engines to which they are attached.

*Whistles.*—A piece of brass-work fixed to the boiler, with a valve to admit steam to it. The steam, on entering the lower part of the whistle, is divided into a very thin concentric space between the outside shell and inside piece, and escapes against a bell-like top, fixed on a centre stalk a little distance from the opening where the steam escapes. This produces the well-known piercing sound of a steam whistle. The size of the concentric part where the steam escapes from, and the depth of the bell part, regulated by the distance between the lower edge of the bell top and upper edge of the concentric part, changes the tones of whistles from a treble to a deep bass.

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*Correction in page 37, line 9.*

*For* "hence $\frac{194{\cdot}828 \times 15 \text{ (stroke)} \times 1122}{1728} = 1897{\cdot}5$ cubic feet," &c., *read*—

$\frac{194{\cdot}828 \times 15 \text{ (stroke)} \times 1122}{1768} = 1854{\cdot}6$ cubic feet of steam per mile; and $1854{\cdot}6 \times 60 = 111{,}276$ cubic feet of steam required for a trip of 60 miles.

We are indebted to George Ross, Esq., Albion Iron Works, Aberdeen, for this correction, and in return make our acknowledgments and thanks.

J. S.
J. W.

# DIVISION A.—LOCOMOTIVE ENGINES.

THIRD PAPER.

# ON THE DIMENSIONS
OF THE
LOCOMOTIVE ENGINE BOILER
IN RELATION TO ITS
EVAPORATIVE POWER.

BY R. ARMSTRONG, C.E.
(LATE OF MANCHESTER.)

" In the fire-box and boiler resides the real source of the power of the engine."—PAMBOUR.

1. THE object of this Paper is to determine the dimensions of a locomotive boiler requisite to furnish steam for any given number of horses' power; and, conversely, the evaporative power of boilers of given dimensions.

Locomotive boilers generally have been too small for the work they have had to perform: hence the tendency to work them at a speed and pressure greater than is safe to those around them. Considering the great extension of railways, and the observant habits of Railway Engineers, it is to be wished that some investigation of a more philosophical kind than the present were directed to this subject, and more especially by those whose connection with railways renders them more competent to the task. No one can be more conscious than the writer of the imperfection of the present step towards the opening up of such an investigation; but he trusts to the circumstance of its being a step in the right direction, and on ground entirely unoccupied by others, as some excuse for the attempt.

The boiler of the railway locomotive steam engine may be shortly defined as a 'cylindrical fire-box boiler' with numerous small tubular flues, and 'direct draft' produced by discharging the 'exhaust' steam through the chimney. This definition is intended to point out, in a popular sense only, what would be the true position of the 'locomotive' amongst the numerous varieties of 'stationary' boilers, if taken from its carriage and set on brick-work.

In applying new methods of computation to such purely practical matters, it will be best to adopt the synthetical mode of giving, as we proceed, the rule and the reason for it at the same time,—trusting to some analogical experiments with stationary fire-box boilers, as a connecting link between the perfect stationary and the perfect locomotive boilers, to make our case complete.

2. The 'egg-ended' cylindrical boiler being the simplest and perhaps the best of all stationary high-pressure boilers, and easily appealed to in corroboration or correction of what we advance, almost every one being conversant with it, it will be best to take it as the ground-work for the data to be employed,—assuming only, for our present purpose, that the plain cylindrical boiler with flat ends is in its evaporating power substantially the same. This is, in fact, identical with the common '*barrel boiler*' of the North of England Collieries; and when set up with a 'through draft' or without side flues, or flues of any kind, as it frequently is, and with the furnace-grate at one end, of the same width as the boiler itself, it brings us one step nearer to the condition of the locomotive, and so far assists the comparison we are instituting.

3. Now it is not a mere matter of opinion, but the result of numerous experiments instituted upon a large scale for *practical purposes only*,—carried on under the inspection of the writer, and recorded in a work especially devoted to the subject of stationary boilers,—that the evaporative power of a boiler of this description, with a certain assignable amount of draft and quality of fuel, depends upon three points, which are as follow:

*First.*—On the area of the fire-grate, or the area of the heating surface immediately over or very near it, exposed to the direct radiation of the heat from the burning fuel.

*Secondly.*—On the whole area or extent of heating surface exposed to the upward action of the flame and hot air within a certain limit.

*Thirdly.*—This limit is, that with a furnace-grate and bars of any ordinary construction, and common coal, there is no appreciable loss of evaporative effect, if the area of the effective heating surface only exceeds that of the fire-grate, or radiant heating surface immediately over it, in the proportion of *nine* to *one*.

Although the above data for stationary boilers have direct relation to their evaporative powers alone, irrespective of their economy, the experience of the last ten years, since the above results were first published, has proved that the proportion of not more than 9 to 1, or a square yard of heating surface to a square foot of fire-bar, is also the most economical; and that by using fuel of a stronger heating quality, or by an increased draft, which amounts to nearly the same thing, even a somewhat less proportion of heating surface is sufficient to render any addition to it unadvisable in *any case*, as costing more than it is worth.

4. Applying the above proportions in practice it was also found, that there was no difficulty in evaporating a cubic foot of water per hour for each square foot of fire-grate, even with inferior coal; and that with the best coal, and careful management in feeding the fire, a proportion approaching to half a square foot was sufficient.

5. Taking the evaporation of a cubic foot of water per hour to be amply sufficient, as it is, for each horse-power in a common Boulton and Watt engine working unexpansively, the power (P) of any boiler to supply such engine with steam may be represented by

$$P = \tfrac{1}{2}(F + S),$$

where $F =$ the area of fire-grate in square feet, and $S =$ the effective area of heating surface in square yards, never greatly differing in amount from F, and never exceeding it. Where, however, S was considerably less than F, though not less than $\tfrac{1}{3}F$,—below which our experiments did not extend,—instead of the arithmetical mean, we found the geometrical mean between F and S to express the nearest approximation to the greatest evaporative effect that could be produced, or

$$P = (FS)^{\frac{1}{2}}.$$

6. We will not assert that it is impossible to find a more correct expression for the relation that subsists between the areas of fire-grate and heating surface when a boiler is producing its maximum effect, than the above empirical formula presents; but it will not be easy to find one more eligible for ready application in practice.

The proportions of heating surface to the fire-grate above given being admitted as correct under the given circumstances of quality of fuel and draft, we may apply them in ascertaining the evaporative power of the boiler taken as our first example; namely,

7. *The Cylindrical Boiler with flat ends.*—In order to obtain a simple expression for the heating surface of this boiler in square yards, let $L =$ length of the boiler in feet, $D =$ the diameter, and $a = 3{\cdot}1416$; then, taking the lower half of the cylindrical boiler to be entirely exposed to the fire, flame, and hot air,—excluding the flat ends, which are generally compensated for by excluding from our measurement a few inches in depth of side surface, of about equal value, which is commonly covered over by the brick-work below the level of the central line of the boiler,—we have $\tfrac{1}{2}aDL =$ the area of the under surface of the boiler in square feet, and

$$S = \frac{1\cdot57\,D\,L}{9} = \frac{D\,L}{5\cdot7};$$

which, taking our previous data of a square yard of effective heating surface as sufficient for a horse-power, is also

$$P = \frac{D\,L}{5\cdot7}.$$

8. The cylindrical boiler under consideration may be supposed to have a diameter of 6 feet, which will conveniently admit a fire-grate under it of 5 feet square, = 25 square feet area; and in order to be arranged in the best proportions for a 25-horse boiler, as before indicated, would require a heating surface of 25 square yards, or

$$P\,(=25) = \frac{D\,(=6)\,L}{5\cdot7};$$

whence $L = \frac{5\cdot7\,P}{D} = 23\cdot75$ feet for the length of the boiler, which is nearly four times the diameter: but as it is expedient to approximate these examples as nearly as convenient to the more general proportions of the locomotive boiler, we may assume that 20 feet will be a preferable length in this case. Its heating surface will then be (Art. 7) $S = D\,L \div 5\cdot7 = 6 \times 20 \div 5\cdot7 = 20\cdot9$ square yards; which, being less than the number of square feet in the area of the fire-grate, the correct value of P is (by Art. 5) $= (F\,S)^{\frac{1}{2}} = \sqrt{25 \times 21} = 23$ horse-power nearly.

9. In pursuance of this investigation, it may now be supposed that for the purpose of increasing the heating surface and consequent economy of this boiler, and for diminishing the quantity of water it contains, in order to bring it nearer the condition of a locomotive, it is determined to put into it a cylindrical flue of 4 feet diameter, passing longitudinally through it from end to end. Supposing also that the fire-grate remains as before, but that instead of the smoke passing direct from below the boiler into the chimney it takes one turn through the inside flue, let us examine the amount and the effect of the additional heating surface which is thus obtained.

10. It has been found by repeated experiments with common square or nearly rectangular-sectioned flues, that the top of the flue only is fully effective in generating steam; the sides, if nearly vertical, having very little effect, and the bottom of the flue still less, or next to none; and that in a circular flue, whatever effect may be due to the bottom and sides, it is amply compensated for by allowing the upper semi-cylindrical portion to be calculated to the full extent of its area as effective heating surface. And when we consider that the smoke and hot air must act against the *inside* or upper concave surface of the flue, in the same manner as they would do against the *outside* or lower convex surface, supposing the flue to be taken out and fixed up as an extension of the boiler, it is evident that

the effective heating surface of the flue cannot be reckoned at less than we have stated: therefore, in computing the effective heating surface of all circular flues, the lower half must be entirely excluded as non-effective.

11. From the above considerations it appears, that the expression for the effective heating surface of the outer shell of the boiler must also be the correct one for that of the inside flue, or $S = DL \div 5{\cdot}7 = 4 \times 20 \div 5{\cdot}7 = 14$ square yards, which, added to the heating surface of the shell, = 21 square yards, as before found, gives 35 yards as the total effective heating surface of the boiler and flue. Such a large additional surface will enable the boiler to produce the full evaporative effect due to its 25-horse fire-grate; and such a boiler for *evaporating purposes only* (though not for working a *stationary* engine) we know from experience to be extremely economical of fuel.

12. The most obvious way that now presents itself to assimilate the condition of this boiler towards that of a locomotive, is to remove the furnace from under the boiler, and to place one with a fire-grate of the same area within the inside flue. This done, the evaporative power and economy of the boiler will remain just the same as before, provided the hot air is compelled to return down and spread itself under the boiler bottom before passing into the chimney. If, however, we discard all the effect to be obtained from applying heat to the external surface, and allow the smoke to pass direct from the inside flue to the chimney, we acquire a still nearer approach to the locomotive principle, and our hypothetical boiler at once becomes the *Trevithick locomotive boiler*, the great forerunner of Stephenson's.

It is certainly true that these proportions of 25 square feet of fire to 14 square yards of surface, making a boiler, according to our views, of $\sqrt{25 \times 14} = 18\frac{1}{2}$ horse-power, would be far from economical. But it only requires to have a 14-horse furnace-grate to make it a good 14-horse boiler for various evaporating purposes; and with a steam dome and a fire-feeding machine it would be equally good as a steam *engine* boiler.

13. The first improvement that suggests itself in the last-named boiler is to take out the large flue and to substitute two smaller ones instead, each of $2\frac{1}{2}$ feet diameter, thus increasing the effective heating surface to ($2\frac{1}{2} \times 2 \times 20 \div 5{\cdot}7 =$) $17\frac{1}{2}$ square yards. This, with a fire-grate in each flue corresponding to the heating surface, would make a good $17\frac{1}{2}$-horse boiler, not very dissimilar in proportions to some of the oldest locomotives.

14. Another variation or extension of the principle of the above '*double-furnaced*' boiler would be its conversion to the condition of the '*circular marine boiler*,' by having the two furnace or main flues made something less in diameter, say 2 feet, so as to allow them to be placed lower down in the boiler for the

purpose of admitting four smaller flues, each of 12 inches diameter, returning from the smoke-box over the top of the former to the chimney. The effective heating surface in this case is again increased to 28 square yards, making, with an adequate area of fire-grate, a boiler of about 28 horse-power.

15. The next point of view in which to place our hypothetical boiler, in its approximation to the locomotive, would be that of a kind called the '*Liverpool Patent*' construction, which became suddenly very popular soon after the opening of the Liverpool and Manchester Railway: they were precisely the same as the last mentioned, or 'circular marine boiler,' only that they were adapted for land purposes, and a fire-box was added. Many of them were made about the time referred to, but they generally failed for want of draft. They were as nearly as possible the same as those called '*Stevens's American Boilers,*' of which some valuable details are given in Mr. Weale's 'Engineer's and Contractor's Pocket Book' for 1848; from which it also appears that to America belongs the honour of first applying them successfully in steam boats, in conjunction with the fan-blast and anthracite coal. Not, however, being in possession of their actual evaporative power in practice, we here give the dimensions of one of a very similar kind, many of which came under our own observation in Lancashire, in 1833, certainly some years antecedent to their re-invention in America.

16. This was a *seven-flued fire-box boiler,* 23 feet long in the cylindrical part by 7 feet diameter, with the addition of the fire-box of 7 feet wide externally by 7½ feet long, making a total length of 30½ feet: the internal fire-box was 6½ feet wide by 7 feet long and 4 feet deep. Of the seven flues, three were direct, averaging 13 inches diameter by 21 feet long, passing from the fire-box to an internal 'take-up,' or smoke-box: from this smoke-box proceeded four return flues, each of 12 inches diameter by 28 feet long, passing over the top of the other three flues, and over the top of the fire-box to the front of the boiler, where the smoke passed out to the chimney, after making one turn under the cylindrical part of the boiler. Two of these boilers were worked for some years at a chimney with a good draft (equalling a pressure of half an inch of water), evaporating from 40 to 50 cubic feet of water per hour with only a moderate consumption of fuel; which was a greatly improved result compared to that obtained from some others, by the same makers, with a greater number of smaller flues, and consequently worse draft.

17. Reverting to our hypothetical boiler of 20 feet by 6, we shall, by putting into it a dozen direct tube flues, each of 9 inches diameter, and adding a fire-box of 6 feet by 5, again increase its heating surface, while the collective cross sectional area of all the tubes is nearly doubled; therefore, with the same chimney or blast, we know that the draft would not be diminished.

The effective evaporating surface of the flues alone, or $S = D\,(= {\cdot}75 \times 12 = 9\,\text{ft.}) \times L\,(= 20) \div 5{\cdot}7 = 31$ square yards, with a fire-grate of 30 square feet in the fire-box, may be considered a good 30-horse boiler.

18. Having proceeded so far to show the increasing capabilities of the locomotive boiler, considered as an evaporating instrument merely, in its gradual conversion from the simple cylindrical stationary boiler to the direct-draft locomotive boiler of Trevithick, and through various forms of construction to the multiflue or 'tubular' fire-box boiler of Stephenson,—computing the power derivable from each alteration, and tracing their nearest analogies to stationary and marine boilers, as grounds for such computation,—we now introduce another element into the calculation, namely, the *radiant heating surface of the fire-box.*

19. In calculating the power of stationary boilers, we have always considered the radiant heating surface as nearly co-extensive with the area of the fire-grate, and therefore the expression for them in any formula for the power as nearly the same: where, however, the area of the fire-grate is small in comparison with the depth of the fire-box, as in a locomotive, the case is very different; for instead of that part of the heating surface in the furnace which is very near the fire being immediately over the latter, as in a common boiler, the sides of the fire-box are, on the contrary, mostly vertical, whilst the part which is horizontally over the fire, namely, the top of the fire-box, is really the farthest off. Now the evaporative value of different portions of this surface must depend in some measure on adventitious circumstances, which will vary a little in different cases, such as the direction given to the current of air through the grate; though Engineers have generally agreed with Pambour in treating it as if it were uniform in its heating effects, calling all the surface exposed to the direct radiation from the burning fuel on the grate, indifferently, '*radiant heating surface;*' whilst the total surface of the tubes or flues, exposed only to the hot air or smoke, has been called '*communicative heating surface.*' As to the communicative surface of the tubes, we have already considered one-half of it only to be really effective in generating steam (Art. 10), for reasons which will presently appear.

20. If we take a square iron box immersed in water, and keep it continually filled with a current of hot air passing through it, in sufficient quantity to keep the water gently boiling, we find that the upper surface, when horizontal, generates more than double the quantity of steam, per unit of area, generated by the sides, when the latter are vertical,—whilst the bottom generates none at all. These facts are evidently quite independent of the action of the hot air on the internal surface of the metallic box, which of course is uniform, and arise entirely from the difficulty there is in the water getting proper access to, or coming into

close contact with, the side surface, (except at a small portion towards the bottom), so as to take the heat up with sufficient facility to become converted into steam. The minute bubbles of steam, as they rise more or less rapidly to the surface of the water, constitute, in fact, the condition of *boiling* or generating steam, as distinguished from *simmering*, or merely heating the water preparatory to boiling. And whilst this steam thus rises freely and unobstructed, and therefore rapidly, from the top of the box, that generated near the bottom or lower portion of the sides, in rising vertically upwards (which it must do generally), is compelled to pass between the surface of the heated iron plate and the water, forming a thin current or stratum, as it may be called, of steam, which by its constant interposition completely prevents the proper access of the water to the heating surface with sufficient rapidity for effective evaporation.

A strong illustration of the above general fact is afforded by inclining the heated box a little sideways, so that one of the sides may incline a very few degrees from the vertical upwards, whilst the opposite side declines at the same small angle from the vertical downwards, when the very great difference in the amount of evaporation becomes strikingly apparent,—the bubbles of steam, as they are formed, rising rapidly from the elevated side, whilst they hang sluggishly against the opposite one, and appear only to be driven off at last by actually *overheating* and injuring the plate.*

21. It is moreover evident that there must be a different evaporative value for every alteration of the angle of inclination of the generating surface; as a variation of 2 or 3 degrees makes a sensible difference in the amount of evaporation from the sides, whilst any difference in the effect produced by the top is not to be perceived even when inclined as much as 20 or 30 degrees from the horizontal. Sufficient, however, for our present purpose is the knowledge of the fact now generally admitted, that the evaporative value of the top surfaces of fire-boxes and flues, even when inclined as much as 45 degrees from the horizontal position, is to that of the vertical, or very nearly vertical surface, as about *two* to *one*.

22. Hence arises a very obvious and ready rule for the practical measurement of the effective surface of all kinds of flues and fire-boxes. It is as follows: When the area of side surface does not exceed that of the top surface in any unit of the length of the flue,—take them together as effective surface, which agrees with the rule already given in respect of circular flues (Art 10); but when the side surface exceeds the top surface, then take half of such excess, and adding it to twice the area of top surface, call the combined amount the effective heating surface.

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* This injury to boiler plates inclined in a wrong position is not so conspicuous in the *copper* fire-box of a locomotive as in the *iron* fire-place of a marine boiler.

It may here be observed, that in several trials with stationary fire-box boilers, using coals, the evaporation produced by each square foot of effective *radiant* surface, measured in the above way, together with a proportional area of communicative surface, was found to be accurately equivalent to that produced by the same area of fire-grate and heating surface in a common waggon boiler, a corresponding consumption of fuel being required in each case.

23. From the above it will appear that there is no need to make any reference to the area of the fire-grate in any calculation of the power of a fire-box boiler, so long as an equal consumption of fuel is effected by a greater or less rate of combustion or otherwise.

Agreeably, then, to these conclusions, we may take each square foot of effective radiant heating surface in the furnace of a fire-box boiler to be sufficient for each horse-power when common coals and the ordinary draft are used. And supposing the normal working condition of the boiler of a locomotive to be that in which little or no power is lost by the contraction of the blast-pipe,—or when the exhaustion of the chimney by the simple discharge of the eduction steam causes an average draft through the furnace equal to that which is produced by a good chimney for a stationary engine, or equal to the pressure of half an inch of water,—the cases are sufficiently analogous to authorize us to use the same method of computation in both.

24. Equations for the heating surface and horse-power of locomotive engine boilers corresponding to those already given (Arts. 7, 8) for stationary boilers are as follow:

$$\mathrm{S} = \frac{d\mathrm{L}}{5{\cdot}7}, \text{ also } \mathrm{P} = c\sqrt{\mathrm{RS}},$$

where $d =$ the collective diameters of all the tubes in feet; $\mathrm{L} =$ the length of the tubes or of the cylindrical part of the boiler in feet; $\mathrm{S} =$ the effective *communicative* heating surface of all the tubes in square yards, never being less than 1; $\mathrm{R} =$ the effective *radiant* heating surface of the fire-box in square feet, which should not to be less than S: where, however, R is less than S, the equation for the power P is simply $\mathrm{P} = c\,\mathrm{R}$; the co-efficient $c$ depending on the combined effect of the blast, and the quality of the coke, to be determined by experiment, but which in the normal state of the locomotive may be considered equal to unity.

25. The problem now is to determine from some actual case the value of $c$ when a locomotive is exerting its maximum effect; for which purpose we may take as an example Mr. Stephenson's patent six-wheeled engine, as given in the last edition of Tredgold on the Steam Engine.

It contains 124 tubes, each of $1\frac{5}{8}$ inch diameter and 7 feet 9 inches long. Hence $d = (1\frac{5}{8} = )\ 1{\cdot}625 \times 124 \div 12 = 16{\cdot}79$ feet, $=$ the collective diameters of all the tubes, and $S = 16{\cdot}79 \times 7{\cdot}75 \div 5{\cdot}7 = 22{\cdot}8$ square yards, = the *effective* area of tube surface.

The total area of the internal surface of the fire-box is 50 square feet, the top being about 10½ and the side surface 39½; therefore 39½ − 10½ = 29, is the excess of the side over the top surface, of which, according to the rule given in Art. 22, we take half = 14½, and adding it to twice the area of the top, we have $R = 14\frac{1}{2} + (2 \times 10\frac{1}{2}) = 35\frac{1}{2}$ square feet for the *effective* radiant surface of the fire-box; and

$$P = c\sqrt{35{\cdot}5 \times 22{\cdot}8} = 28{\cdot}4\,c.$$

Now it appears from Mr. Stephenson's account of this engine, that the extent of its power, with steam at the pressure of 50 lbs. per square inch in the boiler, was about 77 horse-power, the boiler then evaporating 77 cubic feet of water per hour by 8 lbs. of coke for each cubic foot. Whence $c = 77 \div 28{\cdot}4 = 2{\cdot}7$, which gives

$$P = 2{\cdot}7\sqrt{RS}$$

for the horse-power of any locomotive engine boiler on this principle.

26. We will now give practical examples of the converse of the above operation, by which to find the dimensions of a locomotive boiler for a given power; and as the tendency of the last ten years, since the above engine was made, has been to increased speed and higher pressure, consequently giving greater power under the same dimensions, we shall only err on the right side by adopting 3 as a round number, instead of 2·7, for the co-efficient in the expression for the horse-power of this engine; whilst it is certain that the progress of improvement must eventually extend the value of $c$ to 4,–5, or even to 6.

*Example* 1.—Required the dimensions of the tubes and fire-box of a locomotive boiler of 78 horse-power?

The first thing is to fix upon as large a fire-grate and horizontal area of fire-box as the gauge of the rails will permit, which we may suppose to be the same as in the last example, = 10½ square feet, which will also be the area of the top surface of the fire-box. Now we want as many square feet of *effective* radiant surface in the fire-box as is equal to the given power divided by the co-efficient 3, or 78 ÷ 3 = 26; and this 26 feet (= R) must be made up as follows:

| | Square feet of effective surface. | | Square feet of side surface. |
|---|---|---|---|
| Double the top surface = 10½ × 2 . . . | = 21 | containing . . . . . | 10½ |
| Half the remaining side surface to make up 26 | = 5 | requiring . . . . . . | 10 |
| | 26 | | 20½ |

And the total heating surface of the fire-box will therefore consist of 20½ square feet of side added to 10½ of top surface, = 31 square feet, of which only 26 is considered effective.

Then we have only to take a corresponding number of square yards ($= 26$) of effective tube surface to complete the boiler. This may be done variously; but supposing it to be distributed amongst 124 tubes of $1\frac{5}{8}$ inch diameter $= 16{\cdot}79$ feet, collectively $= d$; and since $S = 26 = \frac{d\,L}{5{\cdot}7}$, therefore $L = \frac{5{\cdot}7\,S}{d} = \frac{5{\cdot}7 \times 26}{16{\cdot}79} = 8{\cdot}8$ feet, will be the length of the tubes, which will regulate the length of the cylindrical part of the boiler.

27. Should it be considered that economy of fuel is not required to be carried to so great an extent as the length of tube found in the above example would seem to indicate, or that a less proportion of tube to fire-box surface than 9 to 1 is sufficient,—and that for this or for any other reason the length of tube adopted in Mr. Stephenson's engine is preferred, namely, 7 feet 9 inches instead of 8 feet 9 inches,—we shall now see how much additional surface will be required in the fire-box, in order to admit of the tubes (and consequently the boiler) thus being made one foot shorter without any loss of power.

*Example* 2.—Required the dimensions of the fire-box of a locomotive engine of 78 horse-power, the length of the tubes being fixed at 7 feet 9 inches?

Here, as in the last example, it may be granted that the number of tubes ($= 124$) and their diameter ($1\frac{5}{8}$ inch) are also fixed,—because, in fact, they require to be determined from entirely different considerations, namely, *weight* and *strength* of the parts, subjects that could not be entered upon within the limits of this Paper, involving as they do those of collisions and explosions.

We have $d = 16{\cdot}79$ feet $=$ the collective diameters of all the tubes, as before; and $S = \frac{16{\cdot}79 \times 7{\cdot}75}{5{\cdot}7} = 22{\cdot}8$ square yards, the same as in the first example, which, with a fire-box containing a corresponding number of square feet of effective radiant surface, or $R = 22{\cdot}8$, would only make the boiler equal to $22{\cdot}8 \times 3 = 68{\cdot}4$ ($= P$) horse-power.

But we require the value of R when $P = 78$.

Therefore (by Art. 24) we have $P = c\sqrt{R\,S}$.

Whence $R = \frac{\frac{1}{3}P^2}{S} = 26^2 \div 22{\cdot}8 = 29{\cdot}6$ square feet for the effective radiant surface of the fire-box.

Arranging this precisely in the same manner as in the last example,—

| | Square feet of effective surface. | | Square feet of side surface. |
|---|---|---|---|
| Double the top surface $10\frac{1}{2} \times 2$ . . . . . . | $= 21$ | containing . . . . | 10·5 |
| Half the remaining side surface to make up $29{\cdot}6$ | $= 8{\cdot}6$ | requiring . . . . | 17·2 |
| | 29·6 | | 27·7 |

Hence it appears that the total area of the internal surface of the fire-box consists of 27·7 square feet of side surface + 10½ of top surface, making 38·2 square feet, of which only 29·6, or 77 per cent., is really effective.

And taking the average perimeter of the radiant surface at 12 feet, it gives 27·7 ÷ 12 = 2·3 feet for the effective depth of the internal fire-box.

28. The most direct rules in words, derived from a consideration of the foregoing, and simplified as much as possible, are as follow:

*Rule* 1.—*To find the dimensions of the fire-box.*—Take one-third of the given horse-power for the effective radiant surface in square feet, calling it R, and also one-fourth of R for the top surface of the fire-box: then take five times the top surface for the side surface, which, divided by the horizontal perimeter, gives the depth of the fire-box.

*Rule* 2.—*To find the effective tube surface and length of boiler.*—Take one-third of the given horse-power for the effective communicative heating surface in square yards, calling it S. Multiply S by 5·7, which gives the longitudinal sectional area of all the tubes in square feet; and this area, divided by the collective diameters of all the tubes in feet, gives the length of the tubes, and the length of the cylindrical part of the boiler is nearly the same.

*Rule* 3.—*To find the horse-power of a locomotive boiler.*—Multiply the number of square feet of effective *radiant* heating surface in the fire-box by the number of square yards of effective *communicative* heating surface in the tubes (this number not being greater than the former nor less than 1), and extract the square root of the product: this root, multiplied by the constant number 3, will give the horse-power of the boiler required.

29. Knowing the wide extension of a little practical knowledge of such matters amongst the great mass of our operative engineers to be of more importance than greater refinements of calculation confined to a few, the principal rules given above are converted to a shape suitable for the slide-rule, especially for their use; but it should be observed, that when Hawthorn's slide-rule is used, the slider requires to be reversed as follows:

No. 1.

| | | |
|---|---|---|
| A | Diameters of *all* the tubes in feet = *d*. | 5·7 = constant number or gauge point. |
| Ɔ | Length of each tube in feet . = L. | S = effective tube surface in square yards. |

No. 2.

| | | |
|---|---|---|
| A | ⅓ the horse-power P. | R = fire-box surface in square feet. |
| Ɔ | ⅓ the horse-power P. | S = tube surface in square yards. |

## DIVISION A.—LOCOMOTIVE ENGINES.

FOURTH PAPER.

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# DESCRIPTION OF
# THE
# OUTSIDE-CYLINDER TANK ENGINE

CONSTRUCTED BY

MESSRS. SHARP BROTHERS AND CO.,
OF MANCHESTER.

WITH FIVE ELABORATE ENGRAVINGS AND NUMEROUS WOOD-CUTS OF DETAILS.

BY H. B. BARLOW,
CONSULTING ENGINEER AND PATENT AGENT, DUCIE PLACE, MANCHESTER.

JOHN WEALE, DECEMBER 30TH, 1848.

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**The** author of the following description of Messrs. **Sharp Brothers** and Co.'s Outside-Cylinder Tank Engine wishes to express his thanks to the gentlemen of that firm for their kindness in lending him their valuable drawings: to Mr. **Ramsbottom**, Superintendent of the Longsight Works, he is much indebted for the particulars relating to the consumption of coke, number of miles travelled, and many other practical details; and to Mr. R. **Bodmer**, of Manchester, for the interesting calculations based upon the data contained in these pages.

July 1st, 1848.
Ducie Place, Manchester.

# DESCRIPTION

# OF

# THE OUTSIDE-CYLINDER TANK ENGINE.

THIS engine was made in 1847, by Messrs. Sharp Brothers and Co., of the Atlas Works, Manchester, and in its general arrangement is very similar to the outside-cylinder engines made by the above eminent firm; the principal difference consisting in the tender being dispensed with, and the water tanks, which are usually made a part of the tender, being placed below the boiler and foot-plate of the engine. It will be seen that the box containing the coke is placed on the foot-plate behind the fire-box, and that the brake is situated between the driving and one of the hind wheels of the engine, instead of being applied to the wheels of the tender, as they generally are when a tender is used in connection with the locomotive engine.

Engines of this construction are particularly useful on lines of railway varying from 20 to 25 miles between their termini, as they combine, upon six wheels, all the conveniences of a regular engine and tender, usually made with six wheels each. A considerable saving of time is effected at the stations by the use of these engines, because they can be driven with either end foremost, and consequently do not require to be turned round on the turn-tables when they arrive at the end of their journey, although it is preferable to turn them so as to have the chimney foremost, when there is time for so doing.

The weight of these engines, when provided with their full complement of water and fuel, is 21 tons, and the weight of an ordinary engine and tender of the same power is about 30 tons, the difference being 9 tons. A saving nearly equivalent to the power required to propel three passenger carriages is therefore at once effected by the use of the tank engines.

Messrs. Sharp Brothers and Co. supplied the Manchester and Birmingham section of the London and North-Western Railway Company with two engines of this description in the beginning of May, 1847, and they have been in almost daily use ever since, for taking the passenger trains from Manchester to Macclesfield and other towns in the neighbourhood: they are marked No. 33 and No. 34, and perform on an average 114½ miles every day; that is to say, both the engines together make five journeys to Macclesfield, one journey to Chelford, one journey to Stockport and back, during the day; and in addition they have to come from and return to the Longsight Station, where the engines are all kept. The distances and mileage are as follows:

| | Miles. |
|---|---|
| Distance from Manchester to Macclesfield, 17½ miles, taken ten times for the five journeys, | 175 |
| Distance from Manchester to Chelford, 17 miles, taken twice, | 34 |
| Distance from Manchester to Stockport, 6 miles, taken twice, | 12 |
| Distance from Manchester to Longsight Station, 2 miles, to be taken four times, as each engine makes two journeys, | 8 |
| Total for both engines | 229 |

The following is a statement of the number of miles run by the engine No. 33:

| | | Miles. |
|---|---|---|
| 1847. | May | 2596 |
| ,, | June | 3043 |
| ,, | July | 3152 |
| ,, | August | 3006 |
| ,, | September | 2708 |
| ,, | October | 2898 |
| ,, | November | 2871 |
| ,, | December | 2916 |
| 1848. | January | 1870 |
| ,, | February | 2795 |
| ,, | March | 3367 |
| ,, | April | 2786 |
| ,, | May | 3235 |
| | Total | 37,243 |

miles travelled in the first thirteen months, or 2865 miles per month, taking the average.

If the Sundays, on which days the engines do not perform so many journeys, are taken into calculation, it will be seen that this engine has run nearly 100 miles per day, although travelling only about two-thirds of the usual number of miles in the month of January, in consequence of having been laid up about ten days, while the tires of the driving wheels were being turned true.

## DESCRIPTION OF THE ENGRAVINGS.

Plate I. represents a side elevation of the engine, with those parts belonging to the brake shown in section, to facilitate their explanation.

Plate II. represents an elevation of the same engine, taken from the opposite side, with one of the steam cylinders and one of the force-pumps shown in section.

Plate III. represents a longitudinal section through the centre of the engine, showing the internal construction of the boiler, valve-box, water-tanks, &c., &c.

Plate IV. represents a plan of the engine, with the fire-box and smoke-box in section, and the other parts of the boiler removed, in order to show the construction of the machinery beneath it. There is a line drawn through the centre of the engine, to divide the sectional from the other part.

Plate V. contains four end elevations of the engine;—

Fig. 1 being a section through the smoke-box and steam cylinders.

Fig. 2, a section through the cylindrical part of the boiler, with a complete view of the link motion on the left-hand side, and a section of the guide blocks and cross-head on the right-hand side.

Fig. 3, another section of the boiler, with a section of the force-pumps on the left, and a section of the driving wheel on the right-hand side.

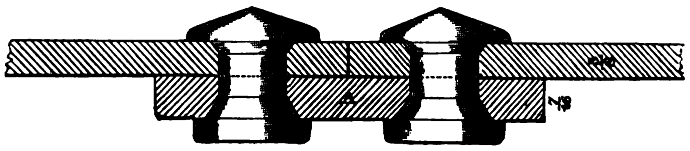
Fig. 4, a section of the fire-boxes on the right-hand side, and a section through the coke-box and one of the water-tanks on the left.

The engravings are all drawn to a scale of ¾ inch to a foot, or one-sixteenth of the real size, and the same letters and figures of reference are used to denote the same parts throughout.

The boiler, being the most important part of a locomotive engine, inasmuch as it generates the steam which is the source of all the motion communicated to other parts of the engine, is therefore the most proper for being first described: it consists in this instance of the usual divisions for containing water, fuel, and steam.

The cylindrical portion of the boiler is 10 feet 3½ inches long and 3 feet 6 inches inside diameter; it is formed of three plates of iron ⅜ths of an inch thick and 3 feet 4⅝ inches wide: these plates are planed at the four edges, and then bent into hoops; the two ends of each plate, being brought into contact so as to form what is technically called a jump-joint, are connected by a plate or welt marked A in figs. 2 and 3 of Plate V., and the complete joint is drawn to half the real size in the margin. The welt A is 4 inches broad, and

Fig. 5.



in length equal to that of the whole cylindrical part of the boiler. The three hoops before mentioned are placed side by side with their planed edges in contact, and they are connected together by circular welts of the same breadth as those marked A, placed over the joints of the hoops forming the cylindrical part of the boiler, to which they are united by $\frac{3}{4}$-inch rivets, similar to those shown in fig. 5, and clearly seen in the longitudinal section of the engine in Plate III. The external fire-box is made of wrought iron plates $\frac{3}{8}$ inch thick; it is nearly square, as seen in the plan view in Plate IV., and sufficiently large to allow 3 inches of water space on every side of the copper fire-box, as seen in the same Plate. The front plate of the external fire-box is connected to the cylindrical part of the boiler by a strong angle iron in the usual manner; the bottom of it is 2 feet 3½ inches below the cylindrical part of the boiler, and the upper part is concentric with the boiler, as seen in fig. 4 of Plate V.

The whole of the internal fire-box is made of copper plates, $\frac{7}{16}$ inch thick, with the exception of that plate near the cylindrical part of the boiler, which is $\frac{3}{4}$ inch thick in that part of it through which the tubes pass, the other portion of the plate being reduced to the same thickness as the other copper plates. The roof and sides of the internal and external fire-boxes are each formed of one plate, as shown in Drawings IV. and V., and the front and back plates have their edges turned inwards, so as to form flanges which are riveted to the outer plate by $\frac{3}{4}$-inch iron rivets. The internal fire-box is fastened at the bottom to the external one by a plate of wrought iron, bent into the shape of a double angle iron marked B (see the sectional elevation, Plate III.), and riveted to both the fire-boxes.

The back plates of the fire-boxes are provided with oval openings 14½ inches wide and 11 inches high, corresponding in size to the fire-door (made of two plates of wrought iron with stays between them), and the space between the back plates and surrounding the oval openings is filled up with a wrought iron ring, faced true on both sides, and securely riveted between the plates. It was formerly customary to set out the back plate of the internal fire-box so as either to do entirely without, or else to require a much thinner ring between the back plates; but the present method is found less prejudicial to the copper of the internal fire-box (which was weakened in the process of setting out), and equally convenient for feeding the fire; whereas in the former construction the steam which accumulated under the ring of the fire-door, by impeding the circulation of the water, caused the copper fire-box to be burnt away in that place.

The whole surface of the internal fire-box, with the exception of the roof and that portion through which the tubes pass, is stayed and connected to the external fire-box by $\frac{3}{4}$-inch copper screw-bolts, placed about 4 inches apart: these bolts are screwed the whole of their length, inserted into holes tapped through both plates to receive them, and riveted up at both ends, to prevent them from getting loose. The roof of the internal fire-box, being flat, requires to be particularly well supported; and this is effected by seven strong wrought iron ribs c, c, seen in Plates III. and V., placed parallel to each other and in a line with the length of the boiler, each rib being riveted to the roof by six rivets. These ribs are 3⅝ inches deep, and 1¼ inch thick, and enlarged at the rivet-holes. The roofs of the internal and external fire-boxes are made to support each other mutually by means of the four upright stays D, bolted above to the strong double angle irons, riveted to the external fire-box, and forked below so as to embrace two of the ribs c, to which they are connected by bolts. The under sides of the ribs are provided with circular facing pieces, ½ an inch high, round each of the rivet-holes: these facing pieces are adjusted to fit the roof of the fire-box, allowing, however, the said ½ an inch space for water to circulate between the roof and the ribs, by which means that portion of the roof immediately under the ribs is kept at the same temperature as the other parts, and the heat equally absorbed by the water covering the roof, except at those places which are in contact with the facing pieces surrounding the rivets, as above mentioned.

It has been observed that the internal fire-box generally lasts about six or seven years, but its durability depends very much upon the quality of the water and coke used, of the copper of which it is made, and upon the precautions taken by the engine driver, who must be very careful to keep the water in the boiler at such a level that the roof of the internal fire-box shall always be covered with water to the depth of from 6 to 7 inches. The engine driver is enabled at all times to ascertain the quantity of water in the boiler by referring to the glass gauge tube E, placed over the firing-door, and seen in Plate I. In case the tube gets broken, the small cocks above and below are closed so as to prevent the escape of the steam and water. The construction of the parts belonging to the glass gauge does not require to be particularly described, as similar gauges are applied to the boilers of nearly all the locomotive and stationary engines in use, and they are therefore well understood by every person having any knowledge of steam engines.

Besides the glass tube, the engine driver has another means of ascertaining the level of the water in the boiler, but it is seldom or never used, except when the glass tube gets broken during the journey. This is effected by the use of three stop-cocks which are screwed into the external fire-box cover, and marked F F′ and F″. The lower cock F is placed 3 inches above the surface of the roof of the internal fire-box, the second cock F′ is placed 3 inches higher, and the upper cock F″ is placed 6 inches higher than the cock F.

These cocks are seen in Plate I., and as they are in communication with the interior of the boiler, it is evident that on turning the handles attached to them either water or steam will escape. As long as the glass gauge tube remains in working order, the engine driver can see how much water he has in the boiler; but when the glass gets broken he is obliged occasionally to try the cocks above mentioned, and if, on turning the cock F he found that steam escaped, he would know that the water was getting too low in the boiler; he would therefore put the force-pumps in gear, and let them work until water came out of both the lower cocks, and steam only out of the cock F″. Should all the cocks discharge water, the engine driver would know that his boiler was too full, and would consequently stop the force-pumps by closing the valve (21), as will be hereafter explained. The use of these cocks is not only attended with a good deal of trouble to the engine driver, but is objectionable from the water coming on the foot-plate, besides which they are much less to be depended upon than the glass gauge; for at night, or when the engine is running at a great speed, it is very difficult to ascertain whether they discharge water or steam.

If, owing to any accident or neglect, the water in the boiler should become so low as to leave the roof of the copper fire-box uncovered, the heat from the fire would melt a leaden plug, $\frac{7}{8}$ths of an inch in diameter, which is screwed into the copper roof of the internal fire-box; and the steam, by rushing through the hole before plugged up with lead, would very soon extinguish the fire.

This engine is provided with 159 brass tubes, of $1\frac{3}{4}$ inch external diameter, reaching from the internal fire-box to the smoke-box: these tubes are 10 feet $7\frac{3}{4}$ inches long and $\frac{1}{10}$th of an inch in thickness; they fit exactly into cylindrical holes made to receive them in the front plate of the internal fire-box and in the back plate of the smoke-box; they are held in the front plate of the fire-box by steel ferrules, turned on the outside slightly conical, so as to form circular wedges, which, when driven into the end of the tubes, expand them, and form a perfectly water-tight joint. The brass tubes must be long enough to project about $\frac{1}{8}$th of an inch through the back plate of the smoke-box, so as to admit of their being secured and made water-tight without ferrules, merely by driving in a steel drift, thereby compressing the tube against the plate of the smoke-box: the projecting end of the tube is then bent over, and hammered up so as to make the joint good. It was formerly considered necessary to drive ferrules into each end of the brass tubes, but it is found by experience that one ferrule at the fire-box end is quite sufficient to hold the tube in its place; consequently, not only is the expense of one set of ferrules saved, but when a tube is worn out it can be replaced by a new one in much less time than it could be done before. Another advantage, of still greater importance than either of the foregoing, is that the tubes are much less liable to get choked with dust and cinders, and much easier to clean out when the ferrule at the smoke-box end is dispensed with, because there is nothing to prevent the dust and small pieces of coke from passing through the tubes and falling into the smoke-box. The average duration of these tubes varies from four to five years, according to the quality of the water and coke used; but those placed near the centre of the boiler are found to wear out a little sooner than the others, owing to their being less completely surrounded by water, in consequence of the steam, which is generated by the tubes below, having to rise up between them.

On examining carefully a tube which has been in use for some time, it will be found that the end near the fire-box, for about 6 or 8 inches in length, is worn very much thinner than any other part; and in nine cases out of ten the leakage takes place close to the fire-box, leaving the remainder of the tube comparatively sound.

The actual difference of the wearing away was ascertained by cutting a tube of 8 feet 4 inches long, which had been in use four years and a half, into ten equal lengths: on weighing the pieces it was found that the

| | | | Ounces. |
|---|---|---|---|
| 1st | length from | the fire-box weighed | 11·75 |
| 2nd | ,, | ,, | 15· |
| 3rd | ,, | ,, | 16·25 |
| 4th | ,, | ,, | 17· |
| 5th | ,, | ,, | 17·25 |
| 6th | ,, | ,, | 17·5 |
| 7th | ,, | ,, | 18 |
| 8th | ,, | ,, | 18·25 |
| 9th | ,, | ,, | 18·5 |
| 10th | ,, | ,, | 18·8 |

From the above it will be seen, that although the metal of the tube is equally thick throughout, when new, the action of the heated gases near the fire-box is so much greater than near the smoke-box, that one end of the tube was 60 per cent. heavier than the other, after being in use the above-mentioned period. This experiment argues against the use of very long boilers, if the vaporizing power of the tube varies in proportion to the action of the gases upon it.

The unequal wearing away of the tubes near the fire-box may be ascribed partly to the mechanical action of the small pieces of coke that are drawn through them by the strength of the draft in the chimney, and impinge with great force on entering the tubes; and partly to the greater quantity of steam generated near the fire-box, the current of which upwards prevents, to a certain extent, the water from coming in contact with the tubes, and thus leaves them at times exposed to the heat of the fire, and unprotected by the cooling influence of the water.

These tubes, being firmly secured at each end to the fire-box and smoke-box, contribute greatly to the strength of the boiler; but as they extend only about

4 inches above the centre of the boiler, the upper part requires additional support: this is given by the eight wrought iron rods G, extending the whole length of the boiler, fixed by cotters to the forked pieces made to receive them, and riveted to the end plate of the boiler and to the back plate of the fire-box. Besides these, there are also four shorter rods, provided with flat ends, riveted to the inside of the cylindrical part of the boiler, and with their other ends riveted to the front plate of the external fire-box, thereby giving the necessary security to the upper portion of the same.

Brass tubes have always been used in the locomotive engines made by Messrs. Sharp Brothers and Co., although it is the opinion of several engineers that iron ones are equally durable and safe: many engine-makers consequently still employ iron tubes very extensively in their boilers, owing to the original cost being so much less than that of brass ones; the relative value being about as 23 to 40,—that is to say, a new brass tube for these engines is worth about 20*s.*; and an iron tube of the same length, reckoning 13*d.* per foot, amounts to 11*s.* 6*d.*

It has been already stated that great difference of opinion still exists respecting the relative merits of brass and iron tubes; and it would be very difficult to arrive at any correct opinion on the subject, unless experiments could be made, under exactly similar circumstances, with iron and brass tubes: it may, however, be said in favour of the latter, that the old iron tubes, when taken out, are comparatively worthless, whereas the brass ones retain about 50 per cent. of their original value.

The smoke-box, or that portion of the boiler which forms the communication between the ends of the tubes and the chimney, is shown in section in Plates III. IV. and V.: it is about 4 feet in width and 2 feet 4¾ inches in length. The back plate into which the brass tubes are riveted is of wrought iron, ⅝ths of an inch thick, and forms the end of the cylindrical part of the boiler, to which it is attached by means of a strong angle iron and rivets; the front plate is ⅜ths of an inch thick, and the roof and sides are made of a single plate of ¼-inch iron, bent over and secured to the angle irons riveted to the back and front plates. A large door is hinged to the front plate, as seen in Plate III., affording, when open, free access to all the tubes in the boiler, and the means of removing the dust and cinders drawn into the smoke-box by the draft created by the blast-pipe. The door can be securely closed by means of six handles, two of which are seen in Plates I. and II.

A circular hole of 15 inches diameter is cut in the roof of the smoke-box, over which is placed the chimney, made of sheet iron, ⅛th of an inch thick, tapering gradually upwards to 12½ inches diameter at the top. The summit of the chimney is 13 feet 3 inches from the level of the rails, and the copper moulding at the top is put on for ornament, as on looking at the section in Plate III. it will be seen that the chimney is continued to the same level as the upper part of the moulding.

The smoke-box contains the pipes H, for bringing the steam from the dome on the boiler to the cylinders, and the pipes I, for conveying the waste steam from the cylinders to the blast-pipe J, all of which will be hereafter described.

It was formerly customary to place a damper in the chimney just below the blast-pipe, with a hole in its centre, large enough to allow the blast-pipe to pass through it: this arrangement has been somewhat modified, inasmuch as the position of the damper is changed, being now applied to the ash-box placed under the fire-grate, the effect being the same in both cases, namely, to check the draft when the engine is going down an incline, or when standing at a station. In Plates II. and III., K represents the damper placed below and in front of the fire-box; it is riveted to three projections, forged on a shaft, on which it hinges, and the damper forms, when down, one end of the ash-pan, the opposite end being another damper marked L, to be used when the motion of the engine is reversed, which is sometimes the case when these engines are returning from a short journey, as for instance, in coming back from Stockport to Manchester.

The damper K is acted upon by means of the flat bar K′, which is brought up along the left-hand side of the fire-box, as seen in Plate II., within reach of the engine driver, who, when he wants to open the damper, lifts the handle provided at the top of the bar K′, until the lower hook catches upon the platform, and lowers it again into the position shown in the drawings, when he wants to check the action of the fire. The damper L is also riveted on to projections forged on a shaft, and has a flat bar L′, reaching through the platform on the right-hand side of the fire-box, as seen in Plate I.: this bar has four notches in it, which come in contact with the under side of the platform, and abut against it, so as to hold the damper in any required position.

These dampers are found much more efficacious than those placed in the chimney; for when both the dampers are closed, the fire is almost entirely deprived of air, and must necessarily be more deadened than when the damper was applied in the chimney, and the whole of the under part of the grate exposed to the atmosphere.

When the damper is placed in the chimney, a great inconvenience is experienced from the escape of the heated gases through the fire-door, rendering it exceedingly unpleasant to remain on the foot-plate while the engine is standing, or when the fire-door is opened to examine the state of the fire.

The dimensions of the internal fire-box are 3 feet 2 inches in length, and 3 feet $3\frac{3}{8}$ inches in width; consequently the surface of the fire-grate is $10\frac{2}{5}$ths square feet: when the fire-box is quite full of coke, it contains about 31 cubic feet, or 7 cwt., which is more than sufficient to take the engine with a train of seventeen carriages from Manchester to Macclesfield without replenishing.

The shape of the grate-bars, and the manner of supporting them, are clearly seen in Plates III. and IV. The ends of the grate-bars near the foot-plate are about 3½ inches higher than the other ends, to give room for the clearing-out plug Y, seen in dotted lines in Plates III. and IV.

The surface of water surrounding the copper fire-box, and therefore directly exposed to the radiated heat, is equal to 58·6 square feet, being the whole internal surface of the fire-box, after deducting the area of the 159 tubes and of the fire-door. The vaporization effected by a certain surface of the fire-box is far greater than that of an equal surface of the tubes: the exact proportion has never been satisfactorily ascertained; but from experiments made by Mr. Robert Stephenson, the proportion has generally been calculated in the ratio of 1 foot fire-box surface equal to 3 feet of the surface of the tubes, although M. De Pambour, in his work on Locomotive Engines, says that he does not consider the difference to be nearly so great. The internal diameter of the tubes being 1·55 inch, will give a surface of 681·3 square feet exposed to the hot gases passing from the fire-box to the smoke-box: in making this calculation, the external diameter of the tube has usually been taken, which in this case would give 769·5 square feet, making a difference of 88 square feet; but it appears more correct to take only the internal surface of the tubes into account, when estimating the quantity of surface exposed to conducted heat.

Generally, the area of the passage for the heated gases to the chimney is calculated by taking the internal area of the ferrule, which in this instance is exactly one square inch, because the interior of the ferrule is 1⅛ inch in diameter. The number of tubes being 159, would give 1·104 square ft. of passage from the fire-box to the chimney. This calculation might be correct when a ferrule is used at each end of the tube, inasmuch as the draft must be impaired by the ferrule in the smoke-box end; but when only one ferrule is used near the fire-box, somewhat more ought to be allowed, because the inside diameter of the tube is 1·55 inch, giving an area of 1·887 inch for each tube, or 2·08 square feet of sectional area for the whole set of tubes. The comparative amount of pressure required to force air through tubes with ferrules at each end, and at one end only, has been ascertained by the experiments made by Mr. Ramsbottom, Superintendent of the Longsight Works. Mr. Ramsbottom found that the quantity of air which can be forced at a pressure equal to a column of water 4 inches high, through a tube similar to those used in this engine, having a ferrule at the fire-box end only, is 10 per cent. greater than that which can be forced through the same tube having a ferrule at both ends. Although it is not practicable to secure the tubes without a ferrule at the fire-box end, Mr. Ramsbottom proved, in the course of his experiments, that the quantity of air which can be forced by the same power through a tube without ferrules is 25 per cent. greater than that which can be forced through a tube with a ferrule at each end. The diameter of the hole in the roof of the smoke-box is 15 inches, and that of the upper part of the blast-pipe is 6½ inches; the difference between the surfaces of the two, leaves exactly one square foot for the passage of the heated gases from the smoke-box into the chimney, the interior of which is 12½ inches diameter at the top, or 0·866 square ft. The chimneys were usually made cylindrical, but it is now customary to make them slightly conical.

*Safety-Valves.*—The construction of the safety-valves has undergone very few changes since locomotive engines were first introduced; they are, however, generally made larger now than they were ten years ago, owing to the increased evaporative power of the present boilers; they are clearly shown in Plate III., and are 3½ inches in diameter. The spring-balance safety-valve P is placed over the centre of the fire-box, and the lock-up safety-valve Q is placed at the top of the steam dome; they are both regulated so as to rise when the pressure of the steam in the boiler exceeds 80 lbs. per square inch, above the atmosphere. The stud serving as a fulcrum to the lever of the valve P, is fixed on a projection from the plate which forms the seating of the safety-valve, and the valve is held down by a pin hinged to the lever, and fitting into a small hole on the top of the valve. The engine driver is prevented from setting the valve to a higher pressure than that fixed upon, by means of a shoulder forged on to the screwed rod which passes through the long end of the lever, as plainly seen in Plates I. and II., and which is so placed that when the thumb screw-nut is in its lowest position, the force of the spring corresponds to that pressure, beyond which the engine is not to be worked, in this case 80 lbs. per square inch. The lock-up safety-valve Q is held down by a strong spiral steel spring, acting upon a spindle, the lower portion of which is conical, and fits into a hole in the valve, and its upper part abutting against a cross head, held fast to the dome by two bolts. Both the safety-valves fit on to conical seatings, mitred to an angle of 45 degrees; but the seatings are very narrow, being thus less liable to become fast, and remaining longer steam-tight than would be the case with broader seatings. The dome on which the safety-valve Q is placed is situated close to the smoke-box, and answers at the same time the purpose of a man-hole; it can be easily removed when the brass casing which surrounds it is taken off; and although the regulator is placed within the steam dome, there is still sufficient room left for a man to enter the boiler, when it is necessary to examine or repair it. This necessity, however, very seldom occurs, as the boiler is cleaned out every two days, and great care is taken always to supply it with clean water: these precautions prevent in a great measure the accumulation of sediment which would otherwise take place, to the great injury of the tubes and other parts of the boiler. The boiler contains about one ton of water when full, and for an average day's work the evaporation will be about seven tons; consequently two days' work will increase fourteen-fold the proportion of sediment contained in the water.

*Blow-off Cock.*—This cock, marked *o* in Plate III., is situated under the platform, and is screwed into the front plate of the external fire-box; a box key fits upon the square end of the plug of the cock, the shank of which projects a few inches through the platform, and has a handle upon it, as seen by dotted lines in Plate IV. The cock *o* is opened every alternate night when the engine has been brought to the shed, and all the water and steam from the boiler blows through it. The next morning the boiler is cleaned out in the following manner: two brass plugs W, seen in Plate I., of 1½ inch in diameter, are screwed into the front of the fire-box: they are placed about 2 feet 2 inches apart, and at such a height that when the hose of a cistern, placed for that purpose above the engine-shed, is put into the holes, previously occupied by the plugs W, the water enters with great force, sends a stream from one end of the boiler to the other, and, the four plugs Y being taken out at the same time, washes out any sediment that may have detached itself from the tubes or other parts of the boiler. These plugs Y are seen partly in Plates I. II. III. and IV.; three of them are placed in a line in front of the fire-box, and are 20 inches from centre to centre; the fourth is placed in the inside of the fire-box, under the grate-bars, as seen in Plate IV. While the water is flowing through the holes before occupied by the plugs Y, the attendant should pass strong wires through the holes to every place within his reach, to assist in getting rid of the sediment which might adhere to and otherwise remain among the copper stays of the fire-box.

In fig. 1 of Plate V. is seen the plug Y′; it is screwed into the back plate of the smoke-box in a line with the bottom row of tubes: this plug is taken out about once a month, when it is necessary to give the boiler a thorough cleaning.

Upon the fire-box is placed a double steam-cock marked *s*, from which descend two small brass tubes, terminating in union joints, which are screwed on to the copper pipes O, forming the connection between the two water tanks M and N.

When the engine is waiting at a station, the steam may be turned into the tanks by opening the cock *s*, so as to warm the water before it is pumped into the boiler: the greatest objection to this contrivance is, that the steam, coming in contact with the cold water, causes a great noise, and so much vibration in the tanks that the joints soon begin to leak; and it is consequently seldom used. *t* represents the steam whistle, placed as usual on the top of the fire-box, and close to the engine driver. The construction of this whistle being similar to that of the whistles employed since locomotives were first introduced into general use, does not require to be minutely described.

*Regulator.*—The steam is admitted into the pipes R and R, which convey it to the cylinders T and T′ through the regulator U, shown in section in Plate III., and in front elevation, on a scale of 3 inches to 1 foot, in fig. 6. The box of the regulator is cast of brass $\frac{5}{16}$ths of an inch thick, and terminates in front in a disc having four openings, through which the steam passes. In the centre of the disc is a round hole $1\frac{1}{4}$ inch in diameter, to admit the spindle of the moveable brass disc, which is provided with openings corresponding with those in the disc of the regulator-box: the moveable disc is made to fit the stationary one with great accuracy, and is held against it by a flat bar of steel and by the pressure of the steam in the boiler. The front elevation in fig. 6 represents the steam-ways about a third open; when these are quite closed, the solid parts of the front disc overlap the openings in the stationary one by $\frac{3}{8}$ths of an inch, so as to make a steam-tight joint. The engine driver is enabled to open or close the regulator by means of the handle V, which is placed in the centre of the fire-box, and keyed on a shaft X, passing through a stuffing-box, fixed to the front plate of the fire-box: near the extremity of the shaft X, a double lever is keyed, to the ends of which two links are attached, which reach upwards and are connected above to projections from the moveable disc of the regulator, as clearly seen in fig. 6. The handle V is furnished with a projection seen in Plate III., whose motion is limited by stops, cast on the front of the stuffing-box on the shaft X: on the handle being brought against the left-hand stop, the regulator is entirely open; and when against the right-hand stop, it is closed. The whole action of the handle V is $\frac{1}{8}$th of a circle from the point where the regulator is entirely closed to where it is wide open. In working the engine, it is very seldom necessary to have the regulator more

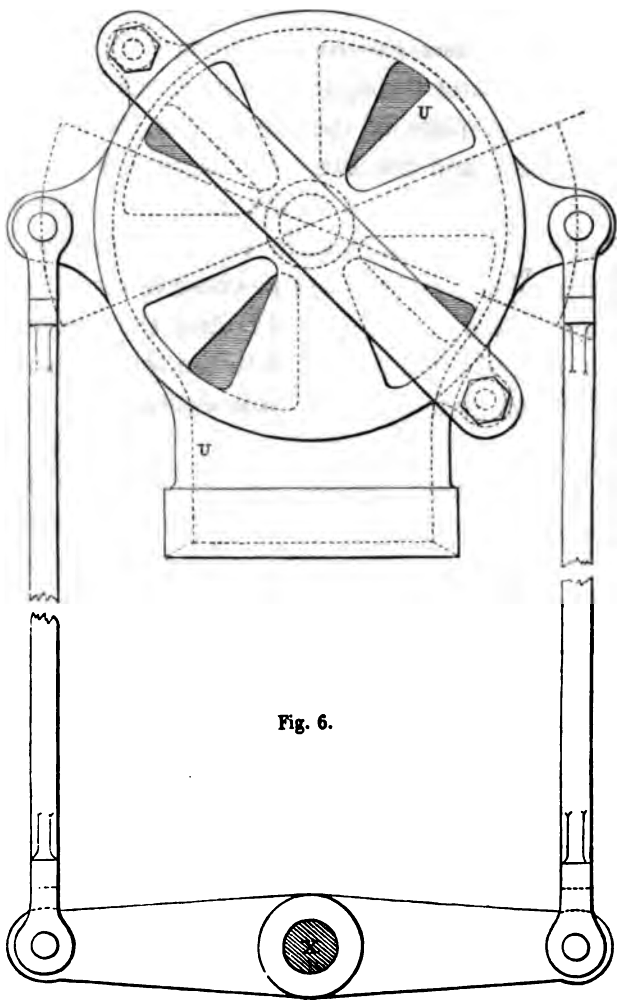


Fig. 6.

than half open, as the engine is less likely to prime when the steam is slightly wire-drawn.

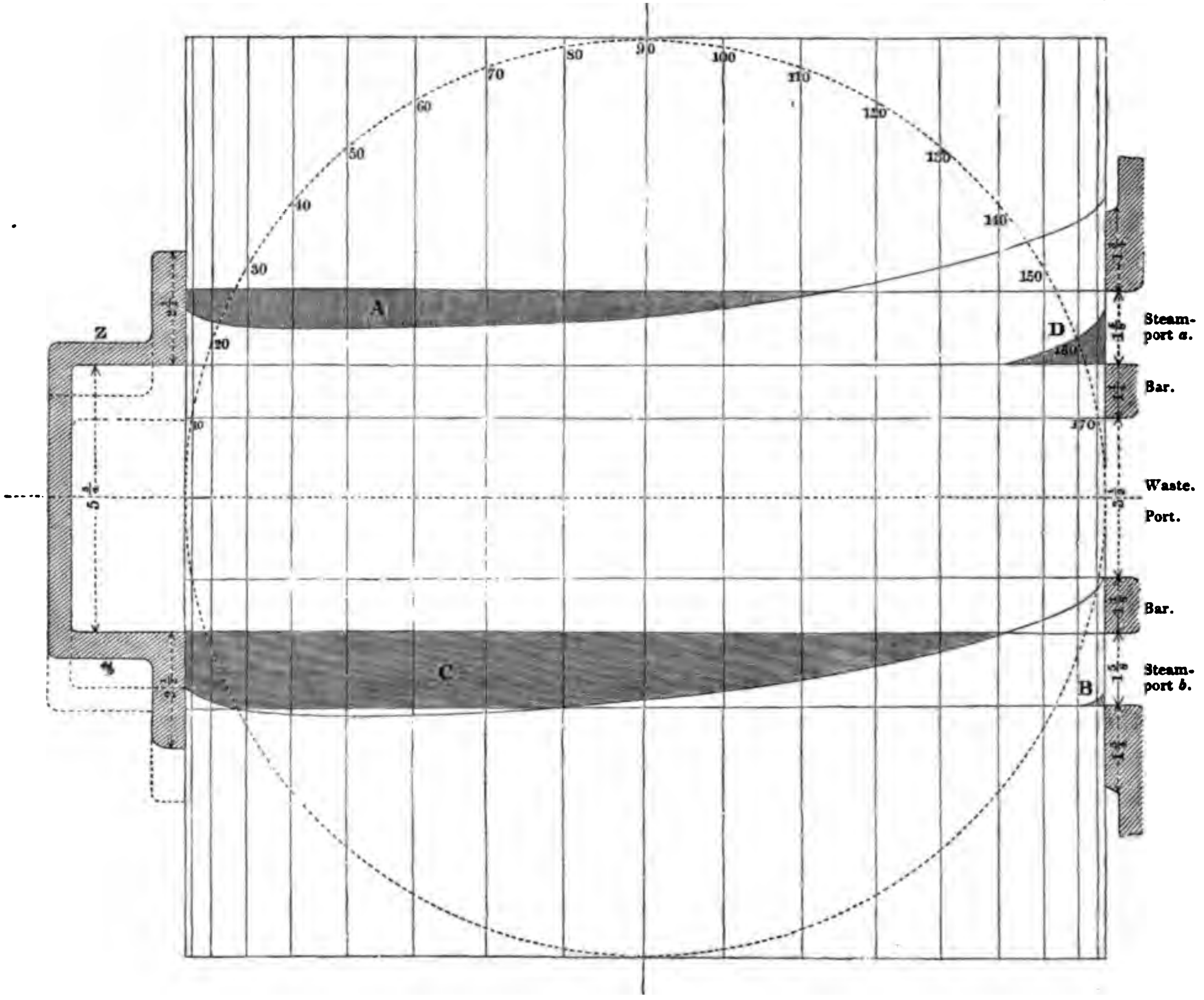
*Steam Chests and Slide-Valves.*—From the regulator U the steam passes into the steam chest through the 5-inch cast iron pipes H′, the elbow of which is bolted to the back plate of the smoke-box, the short double-branch pipe placed in the smoke-box, and the two 4¼-inch copper pipes H attached below to the lid of the steam chest, as shown on the right-hand side of fig. 1 in Plate V., in the sectional elevation, Plate III., and in the plan view on Plate IV. The joint between the copper pipe H and the steam chest is made good by brazing a brass flange to the bottom of the pipe, and then bolting the cast iron loose flange (which had previously been slipped on to the pipe) to the top of the steam chest, with four bolts, as seen in the plan view. This joint is easily broken and re-made in case of repairs. The steam chest is of cast iron, and furnished with a stuffing-box at each end, through which the slide-valve rod works: by this means the slide-valve is made to work more accurately than when only one stuffing-box is used for the valve rod. The slide-valves Z are cast of brass, and of the usual shape, as clearly seen in section, plan, and elevation, in Plates III. IV. and V.; they are connected with the valve rods by a bridle, from which project two lugs, seen best in fig. 1 of Plate V., which lugs serve the purpose of holding two springs (see Plate IV.) acting on the top of the slide-valve, and holding its face in contact with the valve-box, while at the same time they allow the valve to yield, in case any water or steam should be forced through the steam-ways. When the faces of the slide-valve and valve-box wear away, as they will do in the course of time, the bridle which surrounds the slide-valve allows the latter to follow and remain in contact with the box in the usual manner.

During the travelling backward and forward of the slide, each of the steam-ports is alternately uncovered, and the steam allowed to enter and flow into the cylinder; the port is then covered again by the slide, and when the flange, which is 2½ inches broad, has passed over, communicates through the inside of the slide with the waste steam-port, allowing the waste steam to escape into the pipes I, and from thence into the chimney through the blast-pipe. The surface of the slide-valve is 145·125 square inches, and the pressure upon it, reckoning 80 ℔s. per square inch, would be 5⅓ tons: from this must be deducted the amount of pressure occasioned by the blast-pipe, which varies from 2 to 8 ℔s. per inch, according to the opening allowed for the steam to escape.

*Cylinders and Pistons.*—The cylinders T and T′ are placed 6 feet ½ inch apart between their centres, and they are situated in a line with the centre of the driving wheels, or 2 feet 9 inches from the top of the rail to the centre of the cylinders. Both ends of the cylinders are closed by cast iron covers let into them; the ends being enlarged to receive the covers, and to leave besides a recess ¾ of an inch broad at each end, in which any water, dust, or sand may escape that gets into the cylinder. This recess also allows the packing rings of the piston to work beyond the bored-out part of the cylinder, thereby preventing a shoulder being worn by the piston at that point where the motion is reversed.

In consequence of the cylinders being placed outside the framing of the engine, it is necessary to bring the face against which the slide-valve works considerably further from the centre of the cylinder than would otherwise be required. The steam-ways *a* and *b*, reaching in slanting directions from each end of the cylinder to the steam chest, are rectangular passages of $1\frac{5}{8}$ in. wide and 11 in. long, having each an area of 17·875 square inches. These steam-ways are best seen in Plate IV. and in fig. 1 of Plate V.; they are cast of one piece with the cylinder, and the whole is firmly bolted to the side framing by nine bolts, as seen in the drawings. The metal round the cylindrical part is $\frac{3}{4}$ of an inch, and that round the steam-ways $\frac{11}{16}$ths of an inch in thickness. The steam-ports are placed exactly in the centre of the length of the cylinder, so that the steam may, in each case, have the same distance to travel through the steam-ways, in its passage to the front or back of the piston. The centre or waste-port is 11 inches long and $3\frac{1}{2}$ inches broad, with an area of $38\frac{1}{2}$ square inches, or double the area of each of the pipes I, which convey the steam from the back of the piston to the blast-pipe: the steam-ports are exactly the same size as the steam-ways, and their area is equal to one-fourth more than the area of the copper pipes H; the bars between the ports are $1\frac{1}{8}$ inch wide. These dimensions are given in the plan view, Plate IV., where the cylinder and steam chest are shown in section; and the piston is represented in the position it will be in, when the crank-pin is farthest from the cylinder. The slide-valve is then moving in the direction of the arrow, and the port *a* is open $\frac{5}{16}$ths of an inch, admitting steam to the face of the piston: at the same time the eduction-port *b* is open $1\frac{3}{16}$ inch, and the waste steam, after entering the chamber *c*, is carried off to the blast-pipe by the pipes I, as before described: the junction of these pipes with the steam chest resembles that of the pipes H. It has been found from experience that the foregoing is the most advantageous position of the slide-valve at the commencement of the stroke, and the following diagram, fig. 7, drawn to a scale of three inches to a foot, will more fully illustrate it.

The dotted circle represents the motion of the crank-pin, or a circumference of 20 inches diameter, divided into portions of 10 degrees each: the right-hand part of the diagram shows the front plate of the steam cylinder, with the ports marked upon it, and the left-hand side represents the slide-valve itself, the dotted lines representing its position at the time when the piston is at one end of the cylinder: the position of the eccentric rods at that particular moment is shown in Plate IV. On referring to Plate III., it will be seen that the backward and forward eccentrics are each placed at an angle of 113 degrees to a line drawn from the centre of the crank-pin to the centre of the driving shaft. When the slide has arrived at the end of its traverse, it opens the steam-port $\frac{7}{8}$ths of an inch, and admits steam in the proportion indicated by the compartment A of the diagram; and as the slide-valve was already $\frac{5}{16}$ths of an inch beyond the steam-port *a*, when the piston had arrived at the end of the cylinder, it is evident that the small quantity of steam which had entered the cylinder during the time the slide was passing through these $\frac{5}{16}$ths of an inch, must have retarded to a certain extent the advance of the piston: the amount of opposition caused by the lead of the valve is indicated by the small compartment B, in the right-hand corner; and although some opposition must be experienced by the lead, still the effect is so slight, that in practice it is not perceptible, owing to the time required for



charging the cylinder with steam, and to the valve being at that moment nearly at its greatest speed, while the piston itself is moving very slowly, because the crank is turning over the centres; and the advantage derived from having a full supply of steam on the face of the piston, at the commencement of the stroke, more than compensates for the loss caused by the compression above alluded to. The compartment C of the diagram represents the amount of opening of the steam-port *b*, through which the waste steam is escaping from behind the piston: this port has $1\frac{3}{16}$ inch of eduction lead, and was consequently that much open at the time the piston had arrived at the end of the cylinder: on examining carefully the diagram it will be seen that the waste steam has great facility in getting off, so as to oppose the least possible resistance to the advancing piston: during 50 degrees of the circle, or about one-third of the stroke, the port is completely open; and as the slide-valve is 2½ inches deep, the steam has plenty of room to get away into the pipes I. The compartment D shows the amount of opening in the eduction-port for letting off the steam before the completion of the stroke. The steam is cut off entirely at about $\frac{5}{7}$ths of the stroke, the remaining $\frac{2}{7}$ths being completed by the expansion of the steam: the ratio of the expansive action varies as soon as the eduction-port begins to open, or when the piston is at a distance of about 2¼ inches from the end of the stroke, as seen by the compartment D above referred to.

*Pistons.*—These are made according to the plan patented by Mr. Benjamin Goodfellow, and are shown on a scale of 3 inches to the foot in figs. 8 and 9, which represent a plan view and section of the same. In fig. 8 the lid has been removed, in order to show the construction of the spring or inner ring *g*, and other parts. The construction of these pistons is very simple, and they seldom or never get out of repair, unless the packing rings are completely worn out. Upon the end of the piston-rod *d*, which is made of wrought iron, are forged three arms, and the cast iron top and bottom plates *e e* are bolted through holes in these arms: between these plates *e e*, the steel packings *f f* are placed, and, owing to the peculiar shape of the circular wedge spring *g*, are pressed at the same time against the cylinder and the plates *e e* of the piston. The spring *g* is turned rather larger in diameter than the piston for which it is intended, and about 1½ inch of it, when turned, is cut away; the ends are then brought close together, so that its diameter becomes contracted, and when placed between the packings *f*, it expands them in the manner before described. The spring *g* is cut out as seen in fig. 8, the notches diminishing in depth as they approach the centre of the ring, so as to equalize the elastic power of the spring, and make it as nearly uniform as possible on all parts of the circumference of the piston. When the piston is taken to pieces for the purpose of examining and cleaning it, the two set-screws *h* are taken out of the holes into which they are screwed in the piston cover, and two handles screwed into them; the three nuts, which connect the different parts of the piston together, are then removed, and the cover is lifted off by the handles above mentioned; the three rings forming the packings and the spring are then at liberty, and can be taken asunder to be repaired or cleaned when necessary. These pistons are taken to pieces once a week, as it requires very little time to take off the cylinder cover and examine the interior.

Fig. 8.

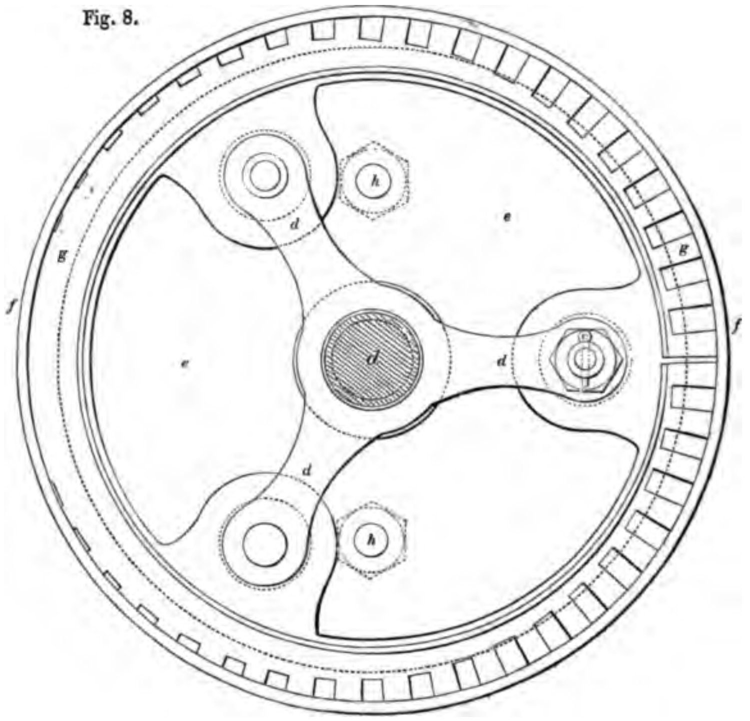
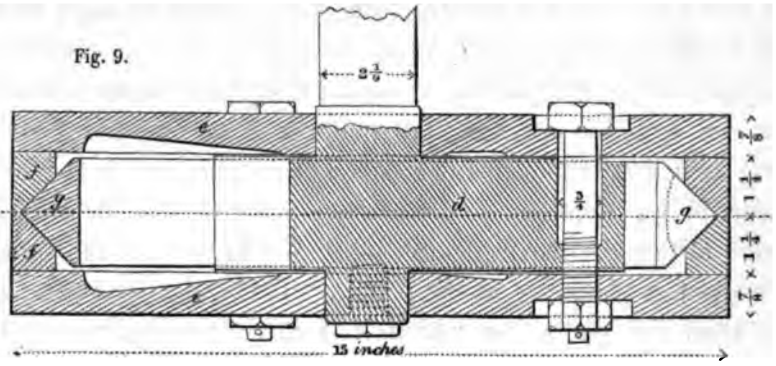


Fig. 9.



To the under side of each cylinder, and at each end thereof, are placed two mud-cocks *i*, for allowing the escape of any water that may accumulate in the cylinder while the engine is standing at a station, or in case of priming: the cocks are placed at such a distance from each end of the cylinder that they open into the recess or groove provided for the escape of dust or sand; and the engine driver can open or shut the whole four cocks simultaneously by moving the flat bar *j* (see Plate II.), which reaches up to the left-hand side of the foot-plate. The plugs of the four mud-cocks are coupled by two small shafts, seen best in fig. 1, Plate V.; and upon each of the shafts an arm is forged, as seen in Plates I. and II., which two arms are united by a link, and connected to the double lever *k* by another link *l*. To the upper arm of the lever *k* the flat bar *j* is hinged, and when the driver wishes to open the cocks *i*, he pulls the bar *j* about 4 or 5 inches towards him, by which motion the arms on the coupling shafts are brought into the positions shown in dotted lines in Plate II., and any water or mud that was in the cylinder is blown out.

It is necessary to clear the cylinders of water before they are greased or lubricated, as the melted tallow used for that purpose would otherwise be blown out with the water, instead of adhering to the piston and interior of the cylinder. The syphons into which the grease is poured for the cylinders are shown in Plates I. and II.; they are screwed into the outside plate of the smoke-box, and a small copper pipe conveys the grease to the cylinder. The stuffing-boxes through which the piston-rods work are similar to those in general use, and do not require to be particularly described. The recesses turned in the lids of the cylinders serve the purpose of affording the necessary room to the heads and nuts of the bolts which connect the front and back plates of the pistons, as seen in figs. 8 and 9. The piston is so placed in the cylinder that there is a space of about a quarter of an inch left at each end between the piston and the cylinder covers.

*Blast-pipe.*—When the waste steam escapes through the port *c*, it is conveyed by the 5-inch copper pipes I, seen in Plates III. IV. and V., to the cast iron blast-pipe J, the lower portion of which is branched out to join the pipes I, and the upper portion is 6½ inches diameter at the junction of the branch pipes, but tapers at the top to a diameter of 5¼ inches, where the steam escapes into the chimney. A moveable hollow cone *m*, the construction of which is seen in section in Plates III. and V., and in plan in fig. 10, slides up and down in the blast-pipe, to enlarge or contract the space allowed for the exit of the steam. A spindle *n* is keyed into the boss of the cone *m*, and passes below through a boss cast on the blast-pipe: a slot is made near the end of the spindle, to admit a lever *p*, keyed on one end of a shaft, seen in fig. 1 of Plate V. This shaft passes through a brass plate fastened on the side of the smoke-box, and has another lever *q* (see

Fig. 10.

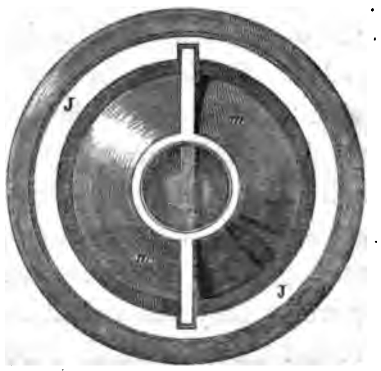


Plate II.), keyed to the other end of it. In Plates III. and V. the cone *m* is represented in the lowest position, or that which allows the greatest opening for the escape of the waste steam, equal in area to 17 square inches. When the engine driver wishes to increase the energy of the draft, he raises the rod *r* (see Plate II.) out of the notch into which it was hooked, and after pushing the rod towards the chimney, allows it to drop again into either of the other notches made in the under side of the rod, which is guided and supported by the hollow rail fixed to the boiler, and hinged to the lever *q* before mentioned. When the rod *r* is hooked into the first notch, the lever *q* would be in the position indicated by a dotted line on Plate II., and the cone *m* would be in the position for contracting as much as possible the opening through which the steam escapes: the area of this opening amounts only to 6·3 square inches; consequently the pressure on the back of the piston would be very much increased. In working the engine, the rod for regulating the opening of the blast-pipe is generally hooked in the third notch from the handle, or with the opening very slightly contracted.

*Eccentrics and Link Motion.*—The four eccentrics *t t′ u* and *u′*, are all keyed on the driving shaft of the engine, which is 5½ inches diameter between the bearings; the eccentrics marked *t* and *t′* give motion to the valve for the left-hand cylinder T, and those marked *u* and *u′* give motion to the valve of the right-hand cylinder T′; they are seen best in the plan view, Plate IV., and in the elevations in Plates III. and V. The eccentrics marked *t* and *u* are for the forward gear, and those marked *t′* and *u′* for the backward gear, or those used when the engine is reversed. As the action is precisely similar in each case, it will be sufficient to describe the eccentrics and link motion for one side of the engine only, it being well understood that each pair of eccentrics is placed exactly at right angles with the pair on the opposite side of the engine, because the crank-pins are placed in the same relative positions in the naves of the driving wheels.

The eccentrics are each made of two pieces of cast iron, fastened together, after their joints have been planed, by two studs screwed into the smaller half, and passing through holes in the larger half; cotters are driven through the projecting ends of the studs, and the halves of the eccentrics are held laterally by the shoulders made in the joint, as seen in Plate III. The centre of the outer circumference being 2½ inches from the centre of the driving axle, consequently the eccentric rods travel through 5 inches of space. The eccentrics are 2⅜ inches broad, and they are each embraced by two brass half-rings, with ribs projecting inwardly, fitting into recesses turned on each side of the eccentrics: these ribs prevent the rings from coming off the eccentrics laterally; the two half-rings are provided with strong lugs, by which they are bolted together, each bolt having two nuts and a split key, to prevent the nuts shaking loose. The thickness of the ring between the ribs is one inch, and the eccentric rods $w$ and $w'$ are each riveted to strong flanges projecting from one of the brass half-rings above mentioned.

The extremities of the eccentric rods are forked, to take hold on each side of the link $x$, which consists of a segment provided with a radial slot, lined with steel, of about 13¼ inches long; the radius with which the centre of the slot in question is described being equal to the length of the eccentric rods, namely, 4 feet 7 inches. The pin which forms the connection between the rod $w'$ and the link $x$ is made of sufficient length to serve as a hinge to the flat bars $y$, seen best in Plates III. IV. and in fig. 2 of Plate V. These bars reach up to and are connected with the arms (1) of the reversing shaft $z$, which extends under the boiler from one side frame to the other: the bearings of this shaft are distinctly seen in Plate II. and in fig. 2 of Plate V. From the shaft $z$, and forged of one piece with it, projects the lever (2) for the counterpoising the arms (1), for the flat bars $y$, and the arm (3) to which the reversing rod is connected. The weight of the counterpoise must be equal to the weight of the links $x$, the flat bars $y$, and part of the eccentric rods; the object of it being to equalize the power to be exerted by the engine driver when he wishes to reverse the motion of the engine: this will be more fully explained hereafter, under the head of '*Reversing Gear.*' A prolongation of the valve-rod, after passing through the stuffing-box in the steam chest before described, is keyed into a hollow cylindrical bush (4) of 2⅞ inches in diameter, as seen in Plates III. and IV. This bush is supported and guided by a bearing (5), seen best on the right-hand side of fig. 2 in Plate V., which is bolted to the side frame of the engine: it terminates in a fork, and the link-block (6) is held between the forks of the bush (4) by means of a steel pin, seen in Plates III. and IV. In putting the link motion together it is necessary to place the link-block (6) in the slot of the link $x$, and to pass the pin into its place when the link, with the block, are in their proper position in the fork of the bush (4). In Plate III. the two eccentric rods and the link are shown in the position for giving the greatest quantity of steam to the forward action of the engine, being the position illustrated by the diagram, fig. 7; and in fig. 2 of Plate V. the link motion is shown in that position which the various parts will assume when the engine is reversed, and the arms (1) and (2) of the reversing shaft $z$ brought into the position indicated by the dotted lines on Plate III.

The bearing (5) is provided with brass steps through which the bush (4) slides, and the end of the valve-rod, to which the bush is keyed, is turned conical, to facilitate the taking asunder and putting together of the parts.

*Reversing Gear.*—The reversing lever (7), seen best in Plates II. and III., vibrates upon a stud which is fixed to a bracket situated on the left side of the engine driver when he stands on the foot-plate. To the end of the reversing lever is hinged one end of the reversing rod (8); the other end of it is connected with the arm (3) forged on the reversing shaft *z*; consequently every motion that is given to the reversing lever (7) is communicated by the rod (8) and shaft *z* to the link motion.

The bracket on which the reversing lever hinges is made with two segments, between which the lever works; the inner segment being provided with thirteen equidistant notches to receive the end of a shot-bolt which is carried along the side of the reversing lever and hinged above to the reversing catch (9), Plate I., the fulcrum of which is on the reversing lever: a spring acts upon the catch (9), and holds the end of the shot-bolt in the notches of the segment before mentioned. When the engine driver wishes to alter the position of the reversing lever, he takes hold of the handle provided at the top, and by acting against the catch (9) at the same time, overcomes the resistance of the spring, so as to lift the shot-bolt out of the notch in the segment, thereby liberating the lever, which is free to move within the range of the segment. In letting go of the reversing lever, the engine driver must take care that the end of the shot-bolt comes opposite one of the notches in the segment. In Plates II. and III. the reversing lever (7) and the other parts of the valve motion are shown in the positions they occupy when the valves are full open, and the engine is in the forward gear: when less steam is required, or when the engine is reversed, the following changes take place in the relative positions of the parts: the slide-valve has now a traversing or backward and forward motion of 3¾ inches, because the link *x* is in its lowest position, and the slide-valve would receive the same amount of traversing motion if the engine were reversed and the link raised to its highest position: when the link is raised half-way, or in such a position that the eccentric rods are each at an equal distance from the centre of the valve-rod, the motion of the valve will be communicated by both eccentrics in an equal proportion, and the valve will only traverse through 2½ inches. The steam in this case being admitted into the cylinder as much before the crank reaches the centre as after passing it, consequently there is no available force from the direct action of the steam; but there is, however, the force produced by the expansion of the small quantity of steam admitted into the cylinder, which is sufficient to keep the engine moving when the reversing lever is in its central position, although it would be quite insufficient to start the engine. By varying the position of the reversing lever (7), and consequently of the link, it is evident that the quantity of steam admitted into the cylinder may be increased or diminished at pleasure within the limits of the link. In working these engines the reversing lever is generally held by the second or third notch of the segment before alluded to, but in going down an incline the lever would be held by one of the notches nearer the centre of the segment; the exact position of the reversing lever depending entirely upon the speed required, the weight of the train, and the road that the engine is running upon, as well as upon the pressure of steam in the boiler and the position of the regulator.

The utility of the counterpoise before mentioned is evident, as, without it, every time the position of the reversing lever (7) is altered, the engine driver would have to overcome or resist the weight of the links *x*, the flat bars *y*, and part of the weight of the eccentric rods *w*.

The advantages resulting from the use of the link motion reversing gear, are, that by varying the position of the reversing lever the steam can be cut off at different parts of the stroke, and worked more or less expansively; the construction is more simple, and it is safer to reverse an engine at a great velocity, when worked by a link motion, than by any of the contrivances previously employed for that purpose. The link motion was first made by Messrs. Robert Stephenson & Co., about six years ago, since which time it has become almost universally adopted by all the makers of locomotive engines in England and on the Continent.

*Cross-heads and Guides.*—To the ends of the piston-rods are keyed the wrought iron cross-heads (10), seen in elevation in Plates I. and II., and in section in Plate IV. and in fig. 2 of Plate V. The cross-head has an open fork, into which the small end of the connecting rod (15) is held by the cross-head shaft (11), which is 2¼ inches in diameter; the upper and lower surfaces of the cross-head are planed to receive the cast iron guide-blocks (12), the length of which is 10 inches, and the width within the heads is 3½ inches. The slide-bars (13) between which the guide-blocks travel are made of steel; they are bolted at one end to flanges cast on the cylinder cover, and at the other end they are bolted to a wrought iron bracket (14), which serves as a bearing for the force-pumps and as a support to the tank M, by means of the brackets riveted to its sides, as will be more fully described with reference to the tanks. The brackets (14) are bolted between two strong angle irons riveted to the framing, as seen in the plan view, Plate IV., and their shape is best shown in fig. 2 of Plate V. The slide-bars are 9 inches apart; they are placed equidistant from and parallel to a line drawn from the axis of the cylinder; and the small recess represented within a few inches of each end is so situated that the guide-blocks reverse their motion when they are about ¼ of an inch over the recess: by this means the slide-bars do not become shouldered as they would do if the above-mentioned recesses were not provided.

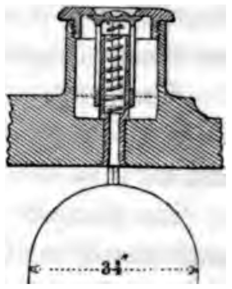
*Connecting-Rods.*—These rods are marked (15), and their length, measuring from the centre of the cross-head to the centre of the crank-pin in the driving wheel, is 5 feet 9 inches; they are of flat wrought iron, with the upper and lower surfaces rounded off, as shown in the section at the left-hand of fig. 2, Plate V. The dimensions of the rods in the middle of their length are about 2¾ inches broad and 2 inches thick; the breadth increases slightly towards the crank-pin, and diminishes in the same proportion towards the cross-head.

The crank-pin is provided with brass steps let into the large end of the connecting-rod, as seen in Plates II. and IV. and in fig. 3 of Plate V. These steps are tightened up and held in their proper position by a cotter which fits into a groove in the step, and secured by the two small set-screws seen in the drawings, and by a split-key driven through it below.

The oil cup for the crank-pin is of a peculiar construction, and was first made by Messrs. Sharp Brothers & Co., about three years ago, since which time it has been copied by many engine-makers.

The cup itself is forged on the connecting-rod, as seen in Plate II. and by the accompanying fig. 11, drawn to a scale of 3 inches to a foot: it is 2 inches in diameter, and in the inside of it a small wrought iron tube is riveted; a light brass valve, having a tubular shank provided with four longitudinal slots, slides loosely on the wrought iron tube, and a brass cap with a hole through it is screwed inside of the cup; the brass valve is held up against the cap by a small spiral spring, placed inside the tube, thereby preventing the escape of oil from the cup.

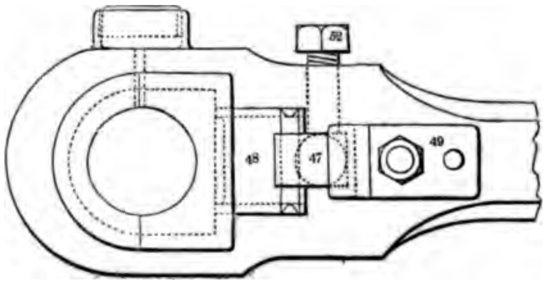
Fig. 11.



When the engine is at work, the motion of the connecting-rod brings the oil against the lid of the cup, from which it runs through the slots in the tubular shank of the valve, and is conveyed to the crank-pin by the iron tube seen in the drawing, without the aid of a wick, which is required in the ordinary oil cups. When the engine is standing, no oil can escape; and in replenishing the cup, the attendant presses upon the valve so as to overcome the pressure of the spiral spring before mentioned, whilst the oil is being poured in; and as soon as the valve is released, the cup is closed again.

The smaller end of the connecting-rod which fits into the fork of the cross-head is also provided with brass steps, fitting on the cross-head shaft (11) before mentioned: these steps are also put together in two halves, as shown in the figs. 12 and 13, drawn to a scale of 3 inches to a foot.

Fig. 12.



The steps are tightened by the action of the wedge (47) against the block (48), and the wedge is drawn up by the nut screwed on the prolongation projecting from its end. The block (48), shown detached in figs. 14 and 15, holds the steps firmly in contact with each other. The small bent plate (49) is a guard to prevent the escape of the wedge (47), in case the screwed end of it should break off when the engine is running. The set-screw (52) is to assist in holding the wedge when it has been tightened up.

Fig. 13.

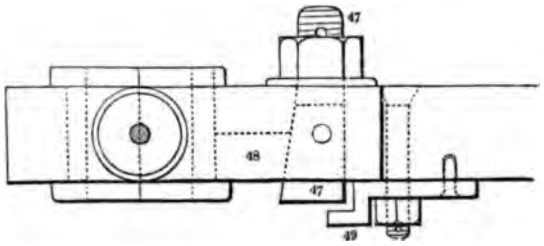


Fig. 14.

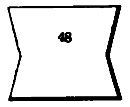
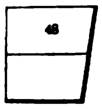


Fig. 15.



Connecting-rods constructed with both ends forged solid, according to the method shown in the drawings, are very superior to those of the ordinary construction, in which the ends are made of loose straps fastened to the connecting-rods by gibs and cotters, and consequently liable to shake loose from the constant motion of the engine.

*Feed-pumps.*—These pumps are for the purpose of drawing the water out of the tanks M and N, and forcing it into the boiler; they are placed outside of the engine framing, and the construction is distinctly seen in Plates I. II. IV. and V.

The plunger (17) is a solid bar of iron, 1¾ inch in diameter, attached to a bush projecting from the cross-head (10), as seen in section in Plate IV.; the centre line of the pumps being placed 3¾ inches from the centre of the piston-rods. The stroke of the pump is 20 inches, corresponding to the stroke of the pistons; consequently every stroke of the pump forces 48 cubic inches of water into the boiler, or a cubic foot in 36 strokes, supposing that there is no leakage or drawing of air: the pump barrel (18) is made of brass, and it is bolted to the wrought iron bracket (14) by three bolts, as seen in fig. 2 of Plate V., and in section in Plate II.: the prolongations of these bolts serve for screwing up the gland of the stuffing-box, through which the plunger works. To the lower side of the pump barrel is cast a flange, to which is bolted a short brass pipe containing the two-inch spherical suction valve (19); the seating of this valve is made on the short brass elbow pipe seen in section in fig. 3 of Plate V., and the guard which prevents the spherical valve, technically called the ball-clack, from rising too much off its seating, is held between the flanges of the elbow and upright pipes by a shoulder clearly seen in the drawings: a bent copper pipe (20) is bolted at one end to the elbow just mentioned, and at the other end to the short brass pipe bolted to the under side of the tank M, containing the valve (21), by means of which the water is let into or shut off from the feed-pumps.

To the upper side of the pump barrel (18) is cast another flange, to which is bolted a brass pipe containing, above, the delivering valve (22), and provided with lugs screwed upon the platform which is carried along each side of the engine:

these lugs give additional firmness to the pumps, and are seen best in the plan view on Plate IV. The water that is drawn from the tank as the plunger recedes from the barrel, is forced, on the return of the plunger, through the upright pipe, and raises the first delivering valve (22), from which it is conducted through a copper elbow pipe to the second delivering valve (23), placed in the box (24) fixed to the side of the boiler: these valves are also prevented from rising too much off their seatings by guards, almost similar to those described as being placed over the suction valve (19), the only difference being that the guards for the delivering valves are screwed from above into the pipes provided for the valves, instead of being held between the flanges, as before mentioned. These guards also answer the purpose of caps, and are easily removed when it is necessary to examine the ball-clacks.

The action of the upper delivering valve is in some measure liable to be obstructed by sediment or dirt from the boiler; it has therefore been found desirable to place a second delivery valve between the pumps and the boiler, so as to diminish the chances of the pumps getting out of order, it being sufficient that one of the delivery valves on each side of the boiler should act, to insure the efficient working of the pumps.

In Plate I., (25) represents the 'pet-cock,' which is placed outside the guard, round the foot-plate, and a similar one is placed in the same position on the other side of the engine: these cocks are connected, by means of small pipes and union-joints, to the valve-box (24), immediately under the ball-clack, and they are for the well-known purpose of allowing, when opened, the escape of any air that may have accumulated under the ball of the delivering valve (23) when the pumps are out of action.

The flat-bar (26), seen best in Plate II., has a handle at one end, by means of which the engine driver can put the feed-pumps into gear, or disconnect them, in the following manner: the other end of the bar (26) is hinged to a lever forged on a short bent shaft (27), seen distinctly on the left-hand side of fig. 3 in Plate V., and in the plan view on Plate IV. This shaft is bent, to give room to the eccentric rod *w* when the motion of the engine is reversed: to the other end of it, and in a line with the centre of the valve (21), placed in the bottom of the tank M, is forged another lever (see also Plate III.), the end of which enters into a slot made in the round rod (28), hinged at the bottom to the valve (21): this valve is of the same description as the safety-valves, only of smaller dimensions, being 2¼ inches in diameter; it is shown in the drawings as being closed, and the plunger would consequently be working in and out of the barrel without drawing water: as soon as the engine driver pulls the flat-bar (26) towards him, the valve (21) is lifted off its face, and water desends into the suction-pipes, from whence it is drawn by the action of the plunger, and forced into the boiler through the valves and pipes before described. The cylindrical piece of cast iron fixed to the end of the rod (28) acts as a weight to hold the valve on its face; the lower edge of it is chamfered off, to allow the free access of water to the valve.

The engine driver always tries to regulate the supply of water in the boiler in such manner that the pumps are only put in gear when the engine is approaching a station: by this means he saves his fuel, as the extra power required to work the pumps assists in checking the motion of the engine.

*Wheels, Framing, Springs, &c.*—This engine is supported upon six wheels, as seen in the drawings, the leading and trailing wheels being 3 feet 6 inches diameter, and the driving wheels 5 feet 6 inches diameter; they are all provided with flanged tires, as seen in the plan view, Plate IV. The tires of the leading and trailing wheels are 5 inches, and those of the driving wheels 5½ inches broad. The spokes and rims are all of wrought iron, and the naves are cast upon the inner ends of the spokes, which are split open to prevent them from shaking loose. In making these wheels each spoke is welded to a piece of flat iron, bent into a segment, equal in length to the distance between the spokes at their outer circumference, 5 inches broad and 1½ inch in thickness. After the nave has been cast around the end of the spokes, the segments are welded together, and form the rim of the wheel, the circumference of which is turned; and the tire, after being bored out, is made hot and shrunk on to the body of the wheel in the usual manner.

The nave of the driving wheel is made with a large projection, into which the crank-pin is firmly driven, and held in its place by a cotter let into the projection of the nave, and passing through the projecting end of the crank-pin. (See plan view, Plate IV.)

In order to counterbalance the weight of the connecting-rod end, the crank-pin, and the projection of the nave, the space between four of the spokes, placed equidistant from a line drawn through the centre of the wheel and of the crank-pin, is filled up with cast iron blocks, 4 inches broad, measured from the inside of the rim towards the centre of the wheel, and in thickness equal to the breadth of the spoke, or 3 inches: these weights are held in their places by wrought iron plates fixed to the two outside spokes, and riveted together through the weights, as seen in Plate I., and in section in Plate IV.

The holes in the driving wheels are 7 inches diameter, and they are bored out to fit very tight on the ends of the driving axle, upon which they are drawn by the force of an hydraulic press, in the usual manner: the wheels are staked on the axle with a steel key, 1½ inch broad and 1 inch deep, let into the axle about one-fourth of its depth, as seen in Plate I.: the tires of the driving wheels, when new, are 1⅞ inch thick in the tread, and they require to be turned up every eight or ten months, owing to the great weight upon them, and to the abrasion that takes place when they slip on the rails.

The leading and trailing wheels are bored out to 6¼ inches, and are staked on their respective axles by steel keys of 1⅛ inch broad, and ⅞ths deep, also seen in Plate I.

The main framing of this engine is formed entirely of two side plates of wrought iron, ⅞ths of an inch thick, extending from one buffer plank to the other, or a distance of 22 feet 3¾ inches; the side plates are connected at their ends to the buffer planks by means of the two pairs of angle irons fastened to them, as seen in the plan view on Plate IV., and in the centre by the traversing bracket (30) formed of a plate of wrought iron, with a strong angle iron riveted to each side of it, as seen in section in Plate III., and in elevation in fig. 3 of Plate V., in which view it will be perceived that the bracket is hollowed out to fit the boiler: the side plates are further united and the boiler supported by means of the angle irons (31) seen in Plates I. and IV. and in fig. 4 of Plate V., riveted to the fire-box by iron rivets, and by prolongations from one row of the copper rivets which form the stays between the internal and external fire-boxes, as shown in the plan view.

On one side of the engine the angle iron (31) rests upon the bracket for supporting the brake, and on the other side upon a piece of angle iron riveted to the framing: they are shown in Plates I. and IV., on referring to which it will be seen that the bolt-holes through them are slotted, to allow for the expansion of the boiler when it is warm.

The back plate of the smoke-box is also connected to the side plates of the main framing by means of angle irons, seen in the plan view.

The side plates of the main framing form a straight line on their upper sides, from one end of the engine to the other, with the exception of a rise over the centre of the driving wheel, as seen by a dotted line in Plate II.: the lower part of them is forked out in three places, to admit the axle-boxes of the wheels. The forks of the leading and trailing wheels are united together below the axle-boxes, by wrought iron bars (32); and the long stay (33), connecting the forks of all the three pairs of wheels, imparts great rigidity to the whole side frame.

The guide blocks for the axle-boxes are all made of cast iron, riveted to the forks of the side plates, as seen in section in Plate IV.; and the axle-boxes slide up and down in them, according to the play of the springs: the upper part of the axle-box is in each case provided with a bell-metal step, to suit the diameters of the bearings of the axles; those for the driving wheels being 5½ inches in diameter and 5½ inches long, and those for the leading and trailing wheels being 5 inches in diameter and 5½ inches long. The construction of these axle-boxes is best seen in Plates II. III. and IV., on referring to which it will be seen that the steps are in the shape of half an octagon, and that they have shoulders at each end, to hold them in the axle-boxes. The axles are lubricated with a mixture of oil and tallow, in the proportion of one pound of tallow to a pint of oil, which is poured into recesses made in the upper parts of the axle-boxes, and descends through holes in the bell-metal steps on to the axles.

The platform which reaches from the fire-box to the smoke-box is 16 inches broad, and is riveted to an angle iron carried along the upper edge of the side frame; another angle iron is riveted to the outer edge of the platform, to give it stiffness, as shown in Plate V.; the splashers of the driving wheels are attached to the platform, which is cut away to admit the wheels, as seen in Plate I. and in fig. 3 of Plate V.

*Springs.*—The side framing, the boiler, and all the other parts of the engine, are suspended upon six springs, bearing upon pivots in the centres of the axle-boxes.

The springs of the driving wheels are each made of thirteen plates of steel, 4 inches broad; they are bound together in the centre by a bridle, 3 inches broad, the lower part of which has a round hole in it to receive the end of the spring pillar, as seen in fig. 3 of Plate V.; and the side framing is suspended to the ends of the springs by screwed adjusting links of 1¼ inch in diameter, and provided with double lock-nuts, as seen in Plates II. and IV.: by setting these nuts, the weight of the engine may be brought to bear more on the leading or driving wheels, as required.

The springs of the leading wheels are each made of fifteen plates of steel, 4 inches broad, connected to the side framing and axle-boxes in the same way as those for the driving wheels.

These springs require to be rather stronger than those of the driving wheels, because they have about the same weight to bear, and suffer more from the inequalities of the road.

The springs of the trailing wheels are made of spiral steel coils, placed in boxes marked (34), as shown in Plates I. II. and III.: the spring pillars in this instance are forked above and enter into the cast iron washer (35), upon which the spiral springs rest: each of the boxes (34) contains two springs, coiled round in opposite directions, the inner spring being made of ⅝-inch square steel, and the outer one of ⅞-inch square steel. A round bar of 1½ inch diameter, made flat below and riveted to the side of the framing, to which it is also hooked, as seen in Plate III., passes up the centre of the springs, and is provided with double lock-nuts above; the upper ends of the springs bear against a cast iron cap (36), which forms the top of the box in which the springs are held: the proportion of weight on the trailing wheels is regulated by the double nuts before mentioned.

The buffers are placed at each end of the engine, because either end may be advancing foremost; they are made of an outside casing of leather, hooped with wrought iron, and filled with three horse-hair cushions.

The centres of the buffers are placed 3 feet 3 inches from the top of the rails, and 5 feet 8 inches apart; these dimensions having been decided upon at a meeting held in October, 1847, at Normanton, by some of the superintendents of the narrow-gauge lines, for the purpose of endeavouring to insure uniformity of construction in the carriage and waggon stock.

To the buffer planks are fixed the four life-guards (37); they reach down to within 1½ inch from the top of the rails, and are intended to remove any large obstacle that might be upon or across the rails.

The draw-hooks (38) are also placed at each end of the engine: a thread is cut upon the shank of the hook, and a corresponding screw is cut into an iron plate, let into the buffer planks; the hooks are provided in front with a double pair of washers, the larger one against which the hook screws, and the smaller one, which has a slot in it large enough to pass over the hook, retains it in the vertical position: these two washers and the plate forming the nut are united together by three small bolts, one of which is seen passing through the buffer plank in Plate III.

In starting the train it is sometimes necessary to put sand on the rail, in front of the driving wheel, so as to increase the adhesion; for this purpose the sand-boxes (45) in Plates I. IV. and V. are placed one on each side of the engine; a pipe provided with a stop-cock (46*) is attached to the under side of each of the sand-boxes, and on the plug of the stop-cock is fixed a lever, by which it is opened or closed. The flat bar (50) reaches from the fire-box to a double lever (51), to which it is hinged, and another flat bar connects the double lever (51) with the lever on the stop-cock. This apparatus is very seldom required on the Macclesfield line, owing to the ballast between the rails being mostly sand; but when the rails are moist, it is necessary, in starting a heavy train, to open the sand-cock, which is done by the engine driver, who pulls the flat bar (50) towards him, and by actuating the levers and bars before described, allows the requisite quantity of sand to fall on the rails.

Having now described all the parts forming what is usually called a locomotive engine, I will proceed to those parts which are commonly carried upon a separate framing and wheels, constituting the tender, but which, as has before been mentioned, form a part of the engine represented in the accompanying plans.

The Water Tanks are marked M and N, and are attached to the framing of the engine. The tank M, placed below the cylindrical part of the boiler, is 7 feet 2 inches long by 2 feet 10 inches deep, and 2 feet 3½ inches broad, and recessed at one end so as to clear the axle of the leading wheels: it is supported at one end by an angle iron, riveted to the back plate of the smoke-box, and at the other bolted to a wrought iron beam extending from one of the side frames to the other, as seen in fig. 3 of Plate V., and supported in the centre by wrought iron brackets, riveted to the tank, and suspended by strong bolts passing through the brackets (14) attached to the side frames. The end of the tank near the driving wheel is further supported by an angle iron resting on a cross stay, bolted to the stays (33), which connect the forks, as seen in Plates III. and IV. and in fig. 3 of Plate V. There is also a beam passing from one side of the tank to the other, to strengthen it, and the tank can be detached in a very short time from the other parts of the engine.

The tank N, placed below the foot-plate and behind the fire-box, is 3 feet 11 inches long, 2 feet 8¾ inches deep, and 4 feet in breadth; it is bolted to the side frames of the engine, and serves as a counterbalance to the weight of the fire-box, which is brought close to the axle of the trailing wheels. The two tanks, when full, contain 480 gallons of water, and are in communication with each other by means of the copper pipes O, which are fastened to the bottom of the tank N and to the sides of the tank M, the latter being placed 4¾ inches lower than the former, and consequently containing about 30 gallons of water when the other tank is empty. The water is conveyed to the tank N through the vertical copper pipe (46) with a funnel-shaped top passing through the coke-box R, and seen in section in Plate III.; the bottom of this pipe is closed with a perforated plate, and its sides, as far as they reach into the tank, are also perforated, so as to allow free ingress to the water, but not to any extraneous matter that might be carried into the pipe. This precaution is necessary to keep the valves in order; and when the perforations become choked up with dirt, &c., the whole pipe can be lifted out of the tank, and cleaned.

The level of the water in the tanks is indicated by a float, seen best in Plates III. IV. and V.; this float consists of a piece of wood about 12 inches square and 3 inches thick, hinged at the end of a long lever, the fulcrum of which is attached to the side of the tank, as seen in fig. 4 of Plate V. A vertical rod is connected to the long lever in the tank, and is guided through a tube in the coke-box, beyond which it projects about 5 inches when the tanks are quite full; the projecting end is graduated, to indicate the level of the water, and is of great use to the engine driver, who knows at a glance when he must take in water, and also when he must stop the supply, during the filling of his tanks. A bent copper pipe, 2 inches in diameter, is fixed on the top of tank M (see Plate III., and in fig. 2 of Plate V.), to allow the escape of the air when the tanks are being filled. The man-holes, shown in front of the tank N, and at the bottom of the tank M, are sufficiently large to enable a man to enter for cleaning out or repairing when necessary.

*Coke-box.*—R represents the coke-box placed over the tank N, and close to the engine driver and stoker, who have about 2 feet 11 inches of space between the fire-box and the coke-box; its dimensions are 6 feet 4½ inches long, 2 feet broad, and 2 feet 11 inches deep, and the cubic contents, after deducting for the casing placed around the copper water tube, is 34 feet. The coke-box will contain half a ton of coke, which quantity, added to the supply in the fire-box, when the fire is made up, is sufficient to take the engine with a train of from eight to ten carriages two journeys to Macclesfield and back. There is a sliding door, 24 inches wide and 16 inches deep, placed opposite the fire-door, through which the coke is taken out of the coke-box and shovelled into the fire-door. A very efficacious method of encouraging the engine drivers to economize the coke has been introduced at the Works of the London and North-Western, and other railways. The weight of coke received by each driver, and the number of miles run by his engine, is entered each day, and the number of pounds of coke to be used by each engine is fixed by the superintendent, according to the size of cylinders, the average weight of the trains, or the speed to be run: at the end of the month, the amount of miles travelled by each engine is divided into the number of pounds of coke consumed; and if the result shows that any engine driver has worked his engine with one or more pounds per mile less coke than the quantity fixed by the superintendent, he receives a premium, varying from 2*s.* 6*d.* to about 30*s.* per month, according to the amount of coke saved.

The engines Nos. 33 and 34 are computed to burn on an average 25 lbs. of coke for every mile.

The consumption was, for

| | |
|---|---|
| No. 33, in April, 1848, | 25·20 lbs. |
| „ May, „ | 25·48 „ |
| No. 34, „ April, „ | 24·58 „ |
| „ May, „ | 24·36 „ |

In taking the average consumption of these engines since they commenced running in May, 1847, the result shows that No. 33 has burnt at the rate of

26 lbs. per mile, and No. 34 has burnt 23 lbs. per mile, although the engines are constructed exactly alike.

The accompanying extract from the books of the Longsight Works represents the average consumption per mile for every month.

| | | No. 33. | No. 34. |
|---|---|---|---|
| 1847. | May, | 30·41 lbs. | 23·08 lbs. |
| „ | June, | 26·13 „ | 18·49 „ |
| „ | July, | 23·38 „ | 17·92 „ |
| „ | August, | 23·84 „ | 19·95 „ |
| „ | September, | 25·43 „ | 20·82 „ |
| „ | October, | 27·24 „ | 20·03 „ |
| „ | November, | 27·46 „ | 25·81 „ |
| „ | December, | 26·38 „ | 26·86 „ |
| 1848. | January, | 25·69 „ | 26·25 „ |
| „ | February, | 26·20 „ | 25·72 „ |
| „ | March, | 26·11 „ | 26·16 „ |
| „ | April, | 25·20 „ | 24·58 „ |
| „ | May, | 25·48 „ | 24·36 „ |

It will be seen from the above, that in July of last year the consumption of No. 34 was under 18 lbs. per mile, which, considering the number of stoppages on the Macclesfield line, proves very much in favour of these engines.

Many of the engines on the Manchester branch of the London and North-Western Railway do not consume nearly so much coke as the above-mentioned sum of 25 lbs.; but the engines running the Macclesfield trains have to stop at nine intermediate stations, and therefore require more coke than engines running trains with fewer stoppages.

*Brake.*—It has already been mentioned that this apparatus is placed between one of the driving and one of the trailing wheels of the engine: the construction of the various parts is best seen in Plates I. and IV. and in fig. 4 of Plate V. To the side of the fire-box are riveted two angle irons, between which is bolted a strong cast iron bracket (39), supported by a wrought iron stay, bolted below to the foot-plate, and above to a projection from the said bracket. The shaft (40) moves in a hole bored through the bracket, and is held in its proper position by a shoulder above, and a loose collar with a pin through it below. The lower part of the shaft (40) is screwed into the nut (41) forged to the end of the strong wrought iron bar (42); to the lower end of this bar, the links (43) are attached, which connect the bar with the swing frames (44): these frames are hinged above to the framing of the engine, and the blocks of wood which form the brakes are first screwed to plates of wrought iron, and then bolted to the swing frames above mentioned.

Upon a square at the upper end of the shaft (40) is fixed the cast iron spoke wheel by which the screw is turned round. In Plate I. the blocks of wood are represented in contact with the driving and trailing wheels of the engine: in order to remove the blocks from the surface of the wheels, the spoke wheel must be turned round so as to unscrew the end of the shaft (40) out of the nut (41), thereby lowering the position of the bar (42), which, in descending, withdraws the brake blocks from the driving and trailing wheels. The screw on the shaft (40) is made about 8 inches long, for the purpose of being able to bring the blocks of wood, even when worn away to the thickness of less than an inch, in contact with the wheels. This brake is found very efficacious in practice, as the screw above and the knee joints below have great purchase on the wheels, and are sufficient to arrest the progress of a train in a very short time. The blocks are made of elm, alder, birch, or poplar wood, and will last generally from two to six days, according to the state of the rails: fresh blocks are always kept ready at the engine-shed, and can be put on in very few minutes by unscrewing two bolts to liberate the plate on which the worn-out blocks are fixed, and bolting on fresh plates with the new blocks attached.

Having thus given a description of the Tank Engine, and furnished a statement of its average consumption of water and fuel, as well as of the work it has to do, it is intended, in conclusion, to show how far the work performed corresponds with the results obtained by calculation.

For this purpose the formulæ developed by M. De Pambour, in his works entitled 'A Practical Treatise on Locomotive Engines,' (2nd edition,) and 'The Theory of the Steam Engine,' have been adopted, as being now generally admitted to be based upon a correct view of the subject.

In his 'Practical Treatise on Locomotive Engines,' p. 338, De Pambour gives, as the general expression of the velocity of a locomotive engine, in miles per hour, the following formula:

$$v = \frac{1}{5280} \cdot \frac{1}{q} \cdot \frac{l}{l+c} \cdot \frac{\text{S.}}{(1+\delta)\,[(k \pm g)\,\text{M} \pm g\,m + u\,v^2] + \text{F} + \frac{d^2 l}{\text{D}}\left(\frac{n}{q} + p + p'v\right)},$$

where the letters represent respectively the following values, viz.:

$v$, the velocity of the engine, in miles per hour.

$q$, the constant quantity ·00000023.

$l$, the stroke of the piston.

$c$, the clearance of the cylinder.

$\delta$, the fraction 0·14 for uncoupled and 0·22 for coupled engines, being the additional friction of the engine, measured as a fraction of the resistance.

$k$, the friction, per ton, of the weight drawn by the engine, a friction expressed in pounds.

$g$, the gravity in pounds, of 1 ton, placed on the inclined plane to be traversed by the engine.

M, the load of the engine, in tons gross.
$m$, the weight of the engine, in tons.
$u v^2$, the resistance of the air against the train at the velocity $v$, a resistance expressed in pounds.
F, the friction of the engine, in pounds.
$d$, the diameter of the cylinders, in feet.
D, the diameter of the driving wheels, in feet.
$n$, the constant quantity ·0001421.
$p$, the atmospheric pressure, in pounds per square foot.
$p' v$, the pressure owing to the blast-pipe, expressed in pounds per square foot.
S, the effective vaporization of the engine, in cubic feet of water per hour. It varies according to the engines, but may, on an average, be valued at ·75 of the total or gross vaporization when there is no steam blowing off at the valves.
S′, the total vaporization of the boiler, at the velocity of the motion, in cubic feet of water per hour.

But since, as has been mentioned in the description, this locomotive engine is provided with a 'link motion,' by which the slides can be made to cut the steam off at certain points of the stroke of the piston, so that the steam acts, to a certain extent, expansively, it is necessary (see De Pambour on the 'Theory of the Steam Engine,' p. 105) to modify the above-mentioned formula as follows:

$$v = \frac{S}{2640\,q} \cdot \frac{H}{(1+\delta)\,[(k \pm g)\,M \pm g m + u v^2] + F + \frac{d^2 l}{D}\left(2\,\frac{n}{q} + p + p' v\right)},$$

where $H = \frac{l'}{l'+c} + \text{hyp. log.} \frac{l+c}{l'+c}$; $l'$ representing that part of the stroke of the piston during which the steam is admitted into the cylinder; all the other letters having the same significations as before.

Now, in order to ascertain what velocity, in miles per hour, the Tank Engine would attain under given circumstances, it will be best to assume it as performing one of its usual trips between Manchester and Macclesfield, with its average train of eight passenger carriages. In this case the numerical values of the various letters will be—

$S = 45$ cubic feet.
$H = 1{\cdot}374$, supposing the steam to be intercepted after the piston has performed ⅘ths of its stroke (see De Pambour on the 'Theory of the Steam Engine,' p. 120).
$k = 6$ lbs. (see De Pambour's 'Practical Treatise on Locomotive Engines,' p. 159).
$g = 0$, the line being, in this case, assumed as level.
$M = 24$ tons, viz. 8 passenger carriages, at 3 tons each.
$m = 21$ tons.
$u v^2$; the value of this expression must be arrived at by approximation, since $v$ is the value sought. The surfaces of the carriages exposed to the resistance of the air amounts to $9 \times 10 + 70 = 160$ square feet, and the value of the term is in this case ($v = 37$ miles) $160 \times 3{\cdot}68 = 588{\cdot}8$ pounds (see De Pambour's 'Practical Treatise on Locomotive Engines,' pp. 129 and 134).
$F = 21 \times 7 + 48 = 195$ pounds (see De Pambour's 'Practical Treatise on Locomotive Engines,' p. 222).

$d = 1{\cdot}25$ foot.

$l = 1{\cdot}666$ foot.

$D = 5{\cdot}5$ feet.

$p = 14{\cdot}7 \times 144 = 2118$ lbs.

$p'v$; the case is the same as with the term $uv^2$. The area of the orifice of the blast-pipe being $= 12{\cdot}57$ square inches, the value of the expression is in this case ($v = 37$ miles) $= {\cdot}0113 \frac{60}{12{\cdot}57} {\cdot}37 = 1{\cdot}993$ lb. per square inch, or $287{\cdot}28$ lbs. per square foot.

Consequently $v = 36{\cdot}98$ miles.

This result will be found sufficiently near the mark, when it is taken into consideration that the trip between Manchester and Macclesfield, and *vice versâ*, is performed in one hour, of which half an hour is taken up by ten stoppages; for since the distance between those two places is 17½ miles, the average velocity of the engine, whilst running, must evidently be 35 miles per hour; and there must be a considerable allowance made for the very frequent interruptions arising from the starting and stopping of the train.

The result of the preceding calculations has, as observed with reference to the value of the term $g$, been obtained on the assumption of the railway between Manchester and Macclesfield being a level, which, however, is not the case; since Macclesfield lies so much higher than Manchester, that the gradient, considered as uniform, would amount to about 1 in 316. It is therefore evident that during the descent of the train the vaporization must be less, and during the ascent greater, than 45 cubic feet per hour; and as from the preceding formulæ it follows that

$$S = \frac{2640\,q}{H}\left[(1+\delta)\left[(k \pm g)M \pm gm + uv^2\right] + F + \frac{d^2\,l}{D}\left(2\frac{n}{q} + p + p'v\right)\right] v,$$

the vaporization during the descent, taking $v = 37$ miles per hour, will be $= 39{\cdot}073$ cubic feet, leaving for the ascent $50{\cdot}927$ cubic feet. Calculating, then, with $S = 50{\cdot}927$, the velocity $v$ for the ascent, it becomes $= 36{\cdot}96$ miles per hour, being nearly the same as that of the descent.

It has been stated in the introductory part of the description, that the engine consumes on an average 7 tons of water per day for a distance of about 120 miles. This mileage is nearly equivalent to seven journeys between Manchester and Macclesfield, each of which must, as above mentioned, be performed in one hour's time; consequently the gross vaporization may be taken at 1 ton, or 2240 lbs. per hour. Now as the vaporization of a locomotive engine, when standing, does not, on an average, amount to more than ⅕th of its vaporization when in motion, it is evident that the 30 minutes consumed in stoppages are equal, with regard to the vaporization, to 6 minutes' working (see De Pambour's 'Treatise on Locomotive Engines,' p. 249); therefore the gross vaporization per hour's work would be $= \frac{2240 \times 60}{36} = 3733$ lbs. And as the effective vaporization amounts on an average to about ·75 of the gross vaporization, the effective vaporization is in this case $= \frac{3733 \times \cdot 75}{62 \cdot 3} = 44 \cdot 94$, say 45 cubic feet, which is the amount at which S has been valued in the first calculation.

On one occasion, when the author accompanied the engine to Macclesfield, the train consisted of

| | |
|---|---|
| 10 cattle waggons, about 5 tons each, | 50 tons. |
| 6 passenger carriages, „ 3 „ | 18 „ |
| 1 milk truck, | 2 „ |
| Total | 70 tons. |

The journey was completed in sixty-eight minutes, or eight minutes beyond the usual time for performing it. If the above journey be reckoned according to the preceding formulæ, and assuming that 45 cubic feet of water are evaporated in an hour, the calculation will show that the engine would take the train of 70 tons at the rate of 29·3 miles per hour. According to practice, however, the distance of 17½ miles was performed in sixty-eight minutes; and when we deduct the usual time for stoppages, the actual speed was $\frac{17 \cdot 5 \times 60}{38} = 27 \cdot 6$ miles per hour.

The difference between the result in practice and the calculation may probably arise from the train, when heavy, requiring rather more time to stop and start than has been set down in these calculations.

The foregoing examples are particularly interesting, as they corroborate to a great extent the correctness of the formulæ laid down by M. De Pambour in his work on Locomotive Engines, first published in 1835, at which time both the pressure of the steam and the speed of the engines were far less than they are at present.

The following extracts from the books at the Longsight Railway Works represent the average consumption of coke per mile, and the number of miles travelled, by the engines No. 33 and No. 34, up to the end of the year 1848.

AVERAGE CONSUMPTION OF COKE.

| | No. 33. | No. 34. |
|---|---|---|
| June | 25·79 lbs. | 23·74 lbs. |
| July | 24·98 „ | 23·33 „ |
| August | 20·91 „ | 20·62 „ |
| September | 19·62 „ | 20·20 „ |
| October | 23·19 „ | 20·89 „ |
| November | 25·39 „ | 25·26 „ |
| December | 25·96 „ | 24·75 „ |

NUMBER OF MILES TRAVELLED.

| | No. 33. | No. 34. |
|---|---|---|
| June | 2662 miles. | 3103 miles. |
| July | 381 „ | 384 „ |
| August | 2962 „ | 858 „ |
| September | 3054 „ | 2101 „ |
| October | 396 „ | 3115 „ |
| November | 2051 „ | 2270 „ |
| December | 2329 „ | 2249 „ |

The author has much pleasure in stating that these engines continue to give great satisfaction to the Engineers of the Macclesfield Branch of the London and North-Western Railway Company, and that Messrs. Sharp Brothers and Co., of the Atlas Works, Manchester, are now constructing several more engines on the same plan.

Ducie Place, Manchester,
March 8th, 1849.

## DIVISION A.—LOCOMOTIVE ENGINES.

FIFTH PAPER.

# OBSERVATIONS

ON

# THE CONSUMPTION OF FUEL AND THE EVAPORATION OF WATER

## IN LOCOMOTIVE AND OTHER STEAM ENGINES.

BY EDWARD WOODS, C. E.
LIVERPOOL.

THE present Paper has for its object to present briefly some of the leading principles which regulate or influence the consumption of fuel in the steam engine,—to apply these principles to the case of the locomotive engine especially,—and, by way of illustration of the intimate dependence of practical results upon them, to state such facts, within the range of the writer's experience, as may be necessary to explain the successive steps by which a gradual but marked improvement in the condition of the locomotive engine, as respects its consumption of fuel, was attained in the course of years at the workshops and on the line of the Liverpool and Manchester Railway.

The immediate cause of motion in a steam engine, and of the force exerted by it on external matter, is the elastic force of steam. The chemical action of the elements brought together in the furnace must be regarded as the remote cause and original source of the forces which are manifested in the steam, and by its means are brought to bear on the piston of the engine.

In this point of view we may consider water, in its conversion from the fluid to the gaseous state, as a convenient depository and carrier of the forces developed in combustion, rather than as the generator of such forces, or as able in any way to add to or diminish from their quantity.

The forces resulting from chemical changes in the forms of matter may be manifested in other ways; as, for instance, in electro-magnetic phenomena and in changes of the volume of gases; but in no way can we at present so readily avail ourselves of them as through the medium of steam.

The elements practically subjected to mutual action in the furnace are, carbon, or compounds of carbon and hydrogen, in a more or less pure state, and the oxygen of the atmosphere. The carbon and hydrogen, placed in contact with oxygen under certain conditions of temperature, undergo various transformations, and the products possess very different properties from the elements out of which they were formed. The process of combination,—combustion, as it is termed,—is attended with the disturbance of the forces under which the equilibrium of the molecules of the burning body is maintained, and is accompanied by the generation of heat.

There is a strong presumption for the existence of a *constant relation between the weight of the substance consumed and the heat it generates;* and there is also ground for the belief that *any definite amount of heat is convertible into, and can be expressed by, an equivalent of mechanical force.* We shall consider these two propositions separately.

### RELATION BETWEEN THE WEIGHT OF FUEL AND THE HEAT WHICH IT GENERATES.

The problem of measuring the heat evolved in the combination of bodies is one of essential importance in connection with many of the arts of life, and has accordingly received the attention of distinguished scientific men. Count Rumford, Crawford, Watt, Black, Lavoisier, Dalton, M. Despretz, M. Dulong, M. Hess, M. Arago, Bezelius, Dr. Ure, are amongst the names of those who have devoted themselves to the inquiry. The results of the earlier experiments must be regarded as approximations towards the more precise data which have been within the last few years obtained; and the conclusions derived by the first labourers in this branch of science have consequently undergone considerable modification.

The experiments of M. Dulong, and of others subsequently, especially those of M. Hess, and of Dr. Andrews of Belfast, appear to have been conducted with the greatest accuracy, and with those precautions, as regards the arrangement of the apparatus, the mode of manipulation, and the reduction of the observations, which are indispensable to insure correct and consistent results.

These experiments may be considered as establishing the following general conclusions.[1]

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[1] See Phil. Mag. July, 1841: 'Summary of Discoveries on the Heating Powers of Bodies.'

*The quantity of heat disengaged by different substances is very different.*

Hydrogen, for instance, produces about four times the heat derived from an equal weight of carbon, and fourteen times the heat from an equal weight of sulphur, in the act of combining with oxygen. The observations of the earlier inquirers, including some by Despretz, indicated a constant relation between the weight of oxygen which entered into combination with the burning fuel and the heat that was evolved; in other words, that a pound of oxygen would generate in each case the same quantity of heat, whether in combining with hydrogen, carbon, alcohol, ether, or other combustibles. This conclusion, which would not be inconsistent with the law expressed, inasmuch as the combining proportions of oxygen and combustible bodies differ greatly for different bodies, is, however, not supported by later experiments.

*The quantities of heat evolved are (nearly) the same for the same substance, no matter at what temperature it burns.*

From this law it follows that the *rate* at which combustion may proceed does not affect the quantity of heat produced by a given weight of fuel. The rate of combustion is proportional to the temperature excited, and to the supply of oxygen delivered. A pound of carbon generates precisely the same quantity of heat, whether it is burnt with rapidity in an intensely heated furnace, under the influence of a powerful blast, or whether it is consumed slowly in an Arnott's stove wherein the supply of oxygen is purposely limited, in order to moderate the intensity of the heat, and prolong the duration of the effect.

Some engineers have believed that the greatest economy in fuel is obtained in cases of very slow combustion, and this mode of applying heat has been adopted with apparent advantage in the so-called 'Cornish boilers;' but if the fact be so, for which reasonable doubt exists, the cause is owing partly to the retention of the heat for a longer time in the spaces around the boiler, and thereby increasing the ratio of the heat absorbed by the boiler to the heat which escapes up the chimney; and partly, perhaps, also, with certain descriptions of coal, to their inability to withstand an intense heat very suddenly applied without undergoing a change of form which is unfavourable to a complete combustion.

The quantities of heat evolved by carbon and hydrogen, as ascertained by Dr. Andrews,[2] whose results accord very closely with those of M. Dulong, are as follows:

| | | | |
|---|---|---|---|
| 1 gramme carbon | evolves | 7900 | (French) units of heat. |
| 1 gramme hydrogen | „ | 33808 | ditto. |

The unit they adopt is the amount of heat required to raise, through one degree centigrade, one gramme of water at the temperature at which the experiment is performed.[3]

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[2] Phil. Mag. Aug. Sept. 1844.

Reducing the results to English weights and measures, and taking the unit as the amount of heat required to raise through one degree Fahrenheit one avoirdupoise pound of water at the temperature of the experiments, we find that in combining with oxygen—

| | | | | |
|---|---|---|---|---|
| 1 pound | of carbon . . . | evolves | 14220 | (English) units of heat. |
| 1 do. | of hydrogen . . | „ | 60854 | do. |

These amounts of heat, applied to the evaporation of water already raised to the temperature of 212° Fahrenheit, assuming that the latent heat of steam of the same temperature is 972°, would produce the following effects:

| | | | | |
|---|---|---|---|---|
| 1 pound | of carbon | will evaporate | 14·6 | pounds water from 212° Fahr. |
| 1 do. | of hydrogen | „ | 62·6 | do.[4] |

These numbers may be therefore taken to express the highest[5] duty which the above-named elementary substances, in their purest state, can possibly accomplish, supposing the entire heat disengaged to be communicated to the water, and none lost by external radiation and conduction.

The duty expressed by the above numbers we shall term the 'theoretical' duty of the fuel in evolving heat, not using the word to denote an effect not yet ascertained in fact, but by way of contrast to the effective working duty of fuel as used in common practice.

It is almost superfluous to state that the necessary conditions for obtaining

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[3] *Table of Results of Dr. Andrews' Experiments on other Substances.* (*Phil. Mag. Aug. Sept.* 1844.)

| | | | | | |
|---|---|---|---|---|---|
| 1 | gramme | carbonic oxide . . . . . . . . . . | evolves | 2431 | units of heat. |
| 1 | do. | marsh gas . . . . . . . . . . . . | „ | 13108 | do. |
| 1 | do. | olefiant gas . . . . . . . . . . . | „ | 11942 | do. |
| 1 | do. | alcohol (sp. gr. 0·7959) at 59° Fahrenheit | „ | 6850 | do. |
| 1 | do. | sulphur . . . . . . . . . . . . . | „ | 2307 | do. |
| 1 | do. | phosphorus . . . . . . . . . . . . | „ | 5747 | do. |
| 1 | do. | zinc . . . . . . . . . . . . . . | „ | 1301 | do. |

1 gramme (French) = ·00220606 lbs. avoirdupoise.
100 degrees centigrade = 180 degrees Fahrenheit.

[4] 14220 units ÷ 972° = 14·6.
60854 do. ÷ 972° = 62·6.

[5] The second measure of heat, here adopted, is a common and convenient one; but it may be necessary to explain that it supposes the heat imparted to the water to be directly and entirely carried off in the steam, and lost, and by no means involves the proposition, that under certain other circumstances,—as for instance when the heat of steam evaporated in one stage of the process is applied to the evaporation of water in a subsequent stage,—the duty of fuel cannot be increased beyond the numbers here given.

the 'theoretical' duty, whether as regards the purity of the fuel and the prevention of extraneous dispersion of heat, can only be fulfilled approximately; but it is nevertheless important to know the ultimate limit of duty, in order to be able to compare it with the actual working duty in each case of the application of fuel in the furnace. The difference will render manifest the amount by which the working duty falls short of the theoretical, and the proportion between the one and the other will be the true measure of the degree of perfection attained in any given boiler and furnace.

> *The heat evolved in the combustion of certain of the compound gases is the same (nearly) as that evolved in the combustion of their constituents separately.*

This law[6] holds good in regard to the gases compounded of carbon and hydrogen. Such, in fact, are the gases distilled from bituminous coal when exposed to a red heat. Let us apply the law to the cases of light carburetted hydrogen and olefiant gas.

Light carburetted hydrogen is composed of

| | | | |
|---|---|---|---|
| Carbon . . . . . | 1 equivalent; | weight | = 6·12 |
| Hydrogen . . . . . | 2 do. | do. | = 2·00 |
| Light carb. hydrogen . | 1 equivalent; | weight | = 8·12 |

Supposing the elements to be burnt separately,

| | | | |
|---|---|---|---|
| The carbon would produce | 48348 | units heat | = 7900 × 6·12 |
| The hydrogen ,, | 67616 | do. | = 33808 × 2 |
| | 115964 | do. | |

which number, divided by the weight 8·12, gives a quotient of 14281 units of heat for each gramme of the compound.

The heat resulting from the combustion of light carburetted hydrogen is in fact (see Table, page 4) 13108 units.

In the case of olefiant gas the agreement is closer. Olefiant gas is composed of

| | | | |
|---|---|---|---|
| Carbon . . . | 4 equivalents; | weight | 24·48 |
| Hydrogen . . | 4 do. | do. | 4·00 |
| Olefiant gas . . | 1 do. | do. | 28·48 |

Supposing the elements to be burnt separately,

---

[6] The correspondence may be conceived to be the closest when the constituent gases, in combining, neither set free nor bind any heat.

| | | |
|---|---|---|
| The carbon would produce | 193392 | units of heat. |
| The hydrogen „ | 135232 | do. |
| | 328624 | do. |

which number, divided by the weight 28·48, gives a quotient of 11539 units of heat for each gramme of the compound.

The combustion of 1 gramme of olefiant gas produces (see Table, page 4) 11942 units of heat.

From the above considerations it would at first sight appear probable that the heating duty of fuel is equal (nearly) to the sum of the separate duties of its constituent combustible elements, supposing these to be fully oxidized; and that when the composition of any given coal or coke is known, its theoretical value in generating heat could be assigned accordingly. But it so happens that the elements out of which the gaseous combustible products of coal are formed exist in coal in the solid state, and require for their conversion into the gaseous state, and before they are in the condition themselves to burn and evolve heat, a large quantity of heat derived from the previous combustion of other parts of the fuel. The quantity of heat thus abstracted has never been accurately ascertained, but is supposed, on a rough computation, to amount to little less than the heat afterwards evolved in the combustion of the gas. It has accordingly been often remarked that those coals which contain the least gas are practically the strongest.

In the absence of direct experiment, we are perhaps not justified in assuming that the heating value of any description of coal containing hydrogen exceeds that of the carbon it contains.

Upon this assumption, the following rule for the heating value of fuel will apply:

Multiply the weight (in ℔s.) of carbon in the fuel by 14·6, and divide the product by the weight of the fuel in ℔s.; the quotient is the theoretical heating power of 1 ℔. of the fuel.

Thus for instance, to take the best Newcastle caking coal, which on an average of specimens was found by Mr. Richardson (see Phil. Mag. 1838, vol. xiii. p. 121).

| | |
|---|---|
| 88· | carbon. |
| 5·2 | hydrogen. |
| 5·4 | azote and oxygen. |
| 1·4 | ashes. |
| 100·0 | |

Carbon 88 × 14·6 = 1284·8

Theoretical duty of 1 ℔. of dry coal is equal to 12·84 ℔s. water evaporated from 212° Fahrenheit.

When it is considered that even in the same mines the quality of the coal varies materially, and that, comparing the bituminous coals obtained from different mines, the proportion of carbon ranges from 60, or even less, to 88 per cent., and the quantity of ashes from 1 to 15 per cent. and upwards, it is obvious that no constant expression of the value can be assumed, but that it is necessary in each case to ascertain the specific composition and assign the duty.

We shall hereafter inquire how far the theoretical and working duties differ, and explain some of the causes of the difference.

### RELATION BETWEEN MECHANICAL FORCE AND THE HEAT WHICH PRODUCES IT.

One of the most important and interesting inquiries relative to the steam engine is that which traces the connection between the heat expended and the force produced.

The method of separate condensation discovered by Watt,—the application by Woolf and Hornblower of the force of expanding steam,—occasioned an important change in the relation of heat to power, and increased in a remarkable manner the dynamical value of fuel.

There are no sufficient grounds for concluding that the improvements in the steam engine subsequently made, and extending even down to the present time, have reached the highest point of the scale. On the contrary, there is strong evidence of the existence of a margin in the field of economy, in the working duty of fuel, ample enough to occupy the husbandry of many labourers for some time to come, and holding out the prospect of a good return.

The recent inquiries of some scientific men, whose attention has been engaged on the subject of the relation between heat and the mechanical effects it produces, have resulted in the discovery of the principle, that the *action of a given amount of heat may be represented by a constant mechanical work performed;* that is to say, by the elevation of a determinate weight through a determinate height.

This constant of work for the unit of heat has been termed '*the mechanical equivalent of heat,*' and expresses the maximum limit of duty which, on the assumption of the truth of the above-named principle, that unit of heat can possibly perform.

It has been shown that, through whatever medium or carrier the mechanical work of heat may be developed or conveyed, whether by means of the vapour of water or other liquids, or by means of atmospheric air or other gaseous matter, the same amount of work is invariably the result.

This constant of work is many times greater than the work hitherto obtained from the best condensing expansive engines.

M. Clapeyron, in his treatise on the moving power of heat, and M. Holtzmann of Manheim, who availed himself of the labours of M. Clapeyron and M. Carnot in the same field, grounding their investigations on the received laws of Boyle or Marriotte, and Gay-Lussac, which express the observed relation of heat, tension, and volume in steam and other gaseous matter, have by theoretical inquiry arrived at the conclusion that—

The mechanical equivalent of the quantity of heat capable of increasing the temperature of 1 ℔. of water by one degree of Fahrenheit's scale is a mechanical force capable of raising a weight, between the limits of 626 ℔s. and 782 ℔s., one foot high.

Mr. Joule, of Manchester, proceeding by entirely different, and independent, and in fact purely experimental methods, concludes that the mechanical equivalent of heat may be taken at 782 ℔s. raised one foot.

The mode of investigation pursued by the continental philosophers, especially by M. Holtzmann,[7] may be thus briefly explained.

They suppose a given weight of steam, or gaseous matter, to be contained in a vertical cylinder formed of non-conducting material, in which is fitted an air-tight but freely moving piston. This piston is pressed downwards by a weight equal to the pressure or tension of the steam or gas. The weight, initial temperature, pressure, and volume being known, a definite quantity of heat from without is supposed to be imparted to the vapour.

The result will be partly an elevation of the temperature of the vapour, and partly an increase of volume, or, in other words, a motion of matter, the pressure or tension remaining the same.

But the result may be represented simply and solely by a motion of the matter (dilatation). For this purpose it is only necessary to allow the vapour to dilate without any loss of its original or imparted heat until it re-acquires its initial temperature.

In this case the final effect is simply dilatation of the vapour under the subsisting pressure; and the mechanical work done is represented by the product of that pressure into the space through which it has been made to recede.

Mr. Joule's estimate of the mechanical equivalent of heat is derived from three distinct classes of experiments.

1st. From the calorific effects of magneto-electricity. (Phil. Mag. 1843, vol. xxiii. p. 263.)

This method is to revolve a small compound electro-magnet, immersed in a glass vessel containing water, between the poles of a powerful magnet; to measure the electricity thence arising by an accurate galvanometer; to ascertain the calorific effect of the coil of the electro-magnet by the change of temperature in the water surrounding it. Heat is proved to be *generated* by the machine, and its mechanical effect is measured by the motion of such weights as by their descent are sufficient to keep the machine in motion at any assigned velocity.

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[7] 'Über die Wärme und Elasticität der Gase und Dämpfe.' Von C. Holtzmann. Manheim, 1845.

2ndly. From the changes of temperature produced by the rarefaction and condensation of air. (Phil. Mag. 1845, vol. xxvi. p. 369.)

In this case, the mechanical force producing compression being known, the heat resulting was measured by observing the changes of temperature of the water in which the condensing apparatus was immersed.

3rdly. From the heat evolved by the friction of fluids. (Phil. Mag. 1847, vol. xxxi. p. 173.)

A brass paddle-wheel, in a copper can containing the fluid, was made to revolve by descending weights. Sperm oil and water as the fluids gave the same result.

The mechanical equivalent of the unit of heat was—

| | | | | |
|---|---|---|---|---|
| As assigned by the | 1st method, | 838 ℔s. | raised 1 foot. |
| „ | 2nd | do. | 795 ℔s. | do. |
| „ | 3rd | do. | 782 ℔s. | do. |

Mr. Joule considers the last method as likely to give a more accurate result than either of the two former; and it is remarkable that the equivalent given by the 3rd method, viz. 782 ℔s., should be identical with the major limit assigned by Holtzmann.

We shall, however, prefer to take the mean adopted by Holtzmann, and to consider THE MECHANICAL EQUIVALENT OF THE UNIT OF HEAT as represented by a WEIGHT OF 682℔s. LIFTED ONE FOOT HIGH; the unit of heat being the quantity required to raise the temperature of a pound avoirdupoise of water one degree Fahrenheit.

### THE WORKING DUTY OF FUEL AS REGARDS THE PRODUCTION OF STEAM.

It has been shown that the amounts of heat obtainable from carbon and hydrogen respectively are such as in the case of the combustion of

1 ℔. of carbon would suffice to evaporate 14·6 ℔s. of water from 212°;

and in that of the combustion of

1 ℔. of hydrogen would suffice to evaporate 62·6 ℔s. of water from 212°;

but that the effect of any heat given out by the combustion of the hydrogen is in great measure neutralized by the absorption of heat necessary to volatilize the hydrogen; and it has been observed that such results are not attainable in practice, in consequence of the diversion of the heat evolved into other channels than those which conduct it directly into the water. To this may be added, that in the common instances of so-called combustion, the combustion is only partial, a portion of the fuel being dissipated without undergoing combustion at all.

Whatever difference may be found practically to exist between the actual and the theoretical duty of the fuel consumed under any given boiler, or given system of firing, may be assigned to one or other of the above causes; and in the comparison of different boilers or modes of firing, the *amounts* of difference, as expressed by the *ratios* between the actual and theoretical duties, would constitute a scale by which the commercial value of any particular apparatus or system of firing can be tested.

In the *Cornish boiler* a duty equal to 10·29 lbs.[8] water, evaporated from the temperature of 212°, has been obtained from 1 lb. of coal.

In the *cylindrical* boilers used in the manufacturing district of Manchester the duty does not appear to exceed 7 lbs. water evaporated from 212° by 1 lb. of coal.

In the *locomotive* boiler it has been found, on the average of an extensive series of experiments on the engines of the Liverpool and Manchester Railway, that the duty of 1 lb. of Hulton or Worsley coke is equal to the evaporation of 8½ lbs. water from the temperature of 212°.

In the larger engines of the Great Western Railway nearly the same duty is obtained. Mr. Gooch[9] states that their last constructed engines (the area of tube surface being from ten to eleven times the area of the fire-box) evaporate 8 to 9½ lbs. water with 1 lb. of coke, according to the rapidity of evaporation; the slowest evaporation with a given sized boiler producing the best result.

The variation in the heating quality of different descriptions of coke from different mines is often very great. In Lancashire the Hulton and Worsley cokes rank highest. Representing the duty of these by 100, it was found by trial that the duty of cokes from six other mines was represented by the following numbers: $76\frac{3}{10}$, $80\frac{3}{10}$, $80\frac{3}{10}$, $81\frac{7}{10}$, 89, $90\frac{1}{10}$. In some instances the inferior duty was partly occasioned by the tenderness of the coke, or inability to withstand the action of the blast; the large pieces breaking up into small ones, and these either falling through the bars or being carried off by the draft.

The above general results in the three most important classes of steam engine boilers will serve to show that considerable loss of heat takes place in each case.

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[8] Report on the Coals suited to the Steam Navy. By Sir H. De La Beche and Dr. Lyon Playfair.

[9] 'Report of Commissioners of Railways respecting Railway Communication between London and Birmingham,' 1848, p. 57.

It does not, however, appear likely that the locomotive boiler can be pushed to perform a much higher duty, taking into account the mechanical limits imposed in its construction. But there is no sufficient reason, except in so far as the comparative cost of alterations and that of anticipated saving in fuel may influence the owner of the boiler in incurring an immediate expense, why the performances of the majority of stationary engine boilers should not be materially improved.

We proceed to consider briefly the circumstances which occasion a diversion of a portion of the heat generated, and dissipation of part of the fuel unconsumed.

### *Diversion of heat generated.*

This may be ascribed chiefly to one or other of the following causes:

1. *Vaporization of the hygrometric water.*

Coal in the state in which it is obtained from the mine contains from 1 to 2 per cent. of water: when exposed to the atmosphere, and especially to rain, it of course imbibes a further quantity, which is greater or less in proportion to the moisture of the air and to the size of the particles of coal; the smaller kinds, and especially what is termed slack, being more retentive than the round coal. This water must be converted into vapour before combustion takes place, and the heat necessary for its conversion must be derived from other portions of fuel undergoing combustion, and is consequently not communicated to the boiler.

Coke being of a much more porous or spongy texture than coal, absorbs frequently as much as 7 per cent. of water in its passage from the oven to the place of consumption in uncovered waggons. A difference in the hygrometric state of the atmosphere has a marked and rapid effect on the amount of hygrometric moisture in coke. Upon accurate weighing, it was found that a quantity of coke delivered in rainy weather, and afterwards exposed for a few days to a drying wind, was reduced from 388 cwt. to 360 cwt. Hence will be seen the advantage of keeping the coke dry until the time it is actually put into the furnace; for not only is there in damp fuel a less quantity of combustible matter than is paid for, unless due allowance be expressly made, but there is a positive reduction of effective power in the combustible portion itself.

Thus to take the instance cited of coke with 7 per cent. of moisture:

100 lbs. of such coke contains 93 lbs. dry fuel.
7 lbs. water.
100

The 93 lbs. dry coke are competent in practice to evaporate 8½ times its weight of water . . = 790 lbs.
But 7 lbs. water contained in the fuel must first be evaporated . . . . . . . . . . . = 7 lbs.

There remains, therefore, as the effective quantity of water evaporated by 100 lbs. of damp fuel, 783 lbs.
Whereas 100 lbs. dry coke evaporate 850 lbs. water.

This is equal to a diminution of effective duty in the proportion of 850 to 783, or about 8 per cent.

In every contract for the supply of coke it is advisable that the contractor should be bound to send it in closed waggons, or waggons covered with water-proof sheets; and the coke dépôts should be so constructed that the waggons may be unsheeted, and the coke weighed out and stocked under cover.

2. *Production of such elevation of the temperature of the air or gases in the chimney as may be required to obtain the draft.*

In the fixed engine furnace the necessary draft is maintained by the differential pressure, as between a column of heated and rarefied air in the chimney-stalk and a column of the colder air without, of equal area and height; the difference of temperature being maintained by the constant accession of heated gaseous matter to the contents of the chimney, which are constantly discharging themselves from the top. It should be the object to render this loss of heat a minimum. The quantity of heat carried off is directly proportional to the quantity of gaseous matter which escapes from the flue into the chimney, and to the temperature at which it escapes. The quantity is a minimum when, for the combustion of any given weight of fuel, no more air has been allowed to pass through the furnace than suffices fully to oxidize the elements of the fuel; and the temperature is a minimum when it does not exceed, unless by a few degrees, the temperature at which the water is being converted into steam of the assigned pressure. When the fire is contained in a box surrounded by water to be heated, as in a locomotive engine, the grate-bar frame should be made to fit closely to the sides of the box; otherwise the surface of the plates adjoining will be insulated from the action of the fire by a stream of cold air rushing upwards between the frame and the box,—a frequent source of waste of fuel.

In the case of the locomotive engine, the draft is obtained mechanically by the application of the steam already generated; and its intensity is liable to considerable variation under differences of pressure in the cylinders, and differences of velocity of the piston.

The current of heated air through the tubes may be made to become so rapid as not to afford the necessary *time* for imparting all the heat which under a milder draft would be taken up by the absorbent surfaces, and a quantity of surplus heat is carried to waste up the chimney.

In former years the draft in the locomotive engine was solely obtained by the action of the blast-pipe. The introduction of the 'close ash-pan,' that is to say, an ash-pan closed below and on all sides except the front, the front being left open to receive a rush of air produced by the velocity of the train, has had the effect of relieving the blast-pipe from a part of its duty, and of saving steam and fuel to that extent. It is however to be observed, that the saving is less on lines of undulating gradients than on those in which a *constant* tension on the fire is needed; for whilst the engine is descending a gradient with steam cut off, it is obviously desirable to stop the passage of air through the fire: but the present form of ash-pan prevents this from being entirely done, and there is a certain waste of fuel on descending gradients to set against the saving on other parts of the road where artificial power is required. The remedy would be to have some ready and simple means of controlling the admission of air: if such means were provided, both before and behind the ash-pan, the engine would generate steam equally well, whether running backwards or forwards.

### 3. *Conduction through solids composing the furnace and boiler, and radiation from the same.*

The greater economy of fuel obtained in the Cornish boilers appears in great measure to arise from close attention to this point; these boilers and furnaces being, in fact, buried in a mass of badly conducting material, such as ashes, brickwork, &c.

The locomotive boiler is particularly exposed to loss of heat from this cause, almost every part being in rapid motion through and in constant contact with the atmosphere, a thin layer of imperfectly conducting material only intervening. It is usual to clothe the boilers with a layer of felt, then with boards, and over them a thin casing of zinc or oil-cloth stretched tightly, painted and varnished to turn off the wet. The high temperature of the steam acting through the boiler-plate often converts the felt or inner surface of the wooden boards into charcoal, which is a still inferior conductor. Notwithstanding these precautions, there is some radiation and waste of heat.

In outside-cylinder engines, the cylinders are unavoidably placed in a position calculated to cool their surfaces and diminish the pressure of the steam within, in which respect they work to some disadvantage as compared with inside-cylinder engines, which have their cylinders enclosed in the hot smoke-box.

### 4. *Dispersion of heated water by priming and leakage.*

This water, suspended mechanically in the steam, and passing with it by the force of the current along the pipes and through the cylinders, without producing any dynamical effect, abstracts as much heat as was expended in raising its temperature from that of the feed-water to the temperature of the issuing steam. The quantity of water, and consequently of heat, thus carried off is dependent chiefly on the incidental circumstances of the purity of the water used, that is to say, its freedom from mud or greasy matter, and of the steam room given above the surface of the boiling water. The steam room in locomotive boilers being necessarily somewhat more contracted than in fixed engine boilers, and the rate of evaporation in respect of the size of the boiler being much greater, there is more tendency to loss of heat from this source.

The best preventive of this loss consists in properly blowing off and cleansing the boilers at prescribed intervals, and in attention to the purity of the feed-water supplied. With these precautions the loss in a well-constructed boiler, with properly arranged steam dome and steam pipes, becomes very trifling, and scarcely appreciable.

Leakages in boilers are often occasioned by the unequal expansion of parts unequally heated, or of parts formed of different metals whose rate of expansion under equal increments of temperature differs; and such leakages are apt especially to occur after sudden and great variations of temperature, as in boilers after being blown off. Instances are well known in which from such causes a whole set of tubes has suddenly begun to leak.

### *Dissipation of unconsumed Fuel.*

In every furnace a certain amount of heat is lost in two ways; first, by an absolute loss of unburnt substance of the fuel, which may be termed a mechanical loss, inasmuch as it proceeds from circumstances connected with the physical condition of the coal, or from imperfection in the mechanical apparatus of the furnace; and, secondly, by the incomplete combustion of the elements into which the fuel has been resolved by heat. The latter has its origin in the want of due regard to the chemical relations of the combining elements.

#### 1. *Mechanical dissipation of the fuel.*

Amongst the ashes which fall from the grate-bars of a furnace there is always present a quantity of unconsumed solid fuel. The quantity depends, other things being equal, on the practical relation between the total area of air spaces and the width between the bars. The area of fire-grate being given, the bars must be arranged so as to present the least possible impediment to the passage of air through the fuel, whilst, at the same time, they afford effectual support even to the smaller pieces. For this reason it is desirable to make the grate-bars as thin as the strength or durability of the material (cast or wrought iron) will allow, adding in depth to make up for deficiency in thickness. The spaces between the bars are adapted to the nature of the fuel. In the case of small coal and slack, the spaces must be more contracted than where rounder coal or coke is employed. Experience soon shows what is the best proportion.

For the best qualities of coke, in the locomotive furnace, the following proportions have been found, on the Liverpool and Manchester Railway, to work with the best effect:

| | |
|---|---|
| Thickness of bars . . . . . | ½ inch. |
| Width of air spaces . . . . . | 1 ditto. |

With these dimensions, the proportion borne by the entire area of air spaces to that of grate surface is as

67 : 100.

The thinner the bars, the more will the proportion be increased. Probably a bar less than ½ an inch thick could not be made durable.[10] About ¾ inch is a common thickness for locomotive furnaces. With such bars, and 1-inch spaces between, the proportion of air space to total area of grate surface is as

57 to 100,

showing a reduction of 10 per cent. of air space as between ½-inch and ¾-inch bars.

Hence the rate of evaporation is diminished, or, if the air spaces be widened to compensate for the extra thickness of the bars, an attendant loss of fuel is incurred.

By proper management, this inconvenience and loss may in great measure be prevented. For this purpose it is only necessary to adapt the quality of the coke, with respect to its dimensions, to the particular duty it has to perform. Engines running with express or other quick passenger trains, and making few stoppages, require a maximum rate of evaporation which can be attained by feeding only with large round coke, thus allowing the air free access to the interior of the burning mass. The rule formerly practised on the Liverpool and Manchester line was to sort the coke from the waggons into three qualities by the rake. The first quality, or large round coke, was delivered to the passenger engines; the second quality, of an inferior size of round coke, to the luggage engines; and the third, of still less dimensions, to ballast engines. Thus the two latter classes of engines performed their work as efficiently as before, and the passenger engines obtained the benefit of the increase of speed which the first quality of coke afforded by increasing the rate of evaporation. The entire coke purchased was thus made to render effective service; for previously there had been much waste occasioned by the fire-men sorting it for themselves on the journey, and throwing out *onto* the road what they considered refuse.

Coke is frequently wasted from want of attention to the fixing of the fire-bars; for unless these are closely wedged or jammed into the frame which supports them, the rapid motion of the engine will cause an incessant friction upon the surface of the fuel at the bottom of the fire, and work a portion of it down into the ash-pan.

The power of fuel to resist mechanical dispersion in the furnace depends on its physical character.

Some kinds of coal contain water in a state of chemical combination, and are apt to split and fly to pieces when heat is applied. The anthracite coals of South

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[10] With ½-inch bars and 1-inch spaces, the destruction of fire-bars on the Liverpool and Manchester Railway, on a mileage of 320,000 miles, during the period extending from January 1st to November 10th, 1841, was 5 tons 16 cwt.; Hulton or Worsley coke alone being used.

Wales are peculiarly subject to this evil. In furnaces of the ordinary construction, and especially in locomotive boilers, it is difficult to use them, as they are apt to break down into powder under the influence of a strong heat suddenly applied. Other kinds, after long exposure to air and weather, appear to undergo a kind of incipient decomposition, which renders them tender and friable. Coke is rendered compact by the process of coking being long continued, producing thereby a sort of fusion between the particles. It is, of course, the manufacturer's interest to employ and replenish his ovens as quickly as possible, and it may therefore happen that the consumers are sometimes sufferers. To withstand the blast of a locomotive furnace, the coking process should be fully completed. Imperfectly coked coal is carried off like chaff through the tubes and up the chimney.

2. *Incomplete combustion of the elements of the fuel.*

Owing to an insufficient supply of air, the volatile products of coal frequently pass off unconsumed, or only partially so. The visible result is the formation of a cloud of smoke from what, before its admixture with air, was an almost invisible gas. This gas, or, at the least, the inflammable part of it, is a compound of carbon and hydrogen united in one or more definite proportions. If oxygen be presented to the gas at a time when its temperature is high enough for the forces of affinity to have full play, but in quantity insufficient to saturate the whole of the carbon and hydrogen, the hydrogen unites with the oxygen before the carbon is taken up, and the carbon is deposited, or rather separated, in the form of smoke.

It would be out of place here to refer to the subject of the prevention of smoke in furnaces, further than to state that a judicious application of the principle of a direct and well-regulated admixture of air with the heated gases, as they are distilled off from the fuel, appears not only to diminish very largely the quantity of smoke evolved from the furnace chimney, but also to effect some saving in fuel. According to Mr. Houldsworth's experiments, reported by Mr. Fairbairn in the 'Report of the British Association' (1844, page 109), an advantage of 12½ per cent. was obtained on the average by the repeated admission of air through apertures behind the bridge. In some cases even a higher duty is said to have been observed.

The reason why the additional heat generated in the full combustion of the gaseous products falls short of the estimates held out by the advocates of different systems of smoke prevention, appears to be that the heat employed in volatilizing the gaseous products is nearly as great as the heat evolved in the subsequent combination of those products with oxygen.

A sufficient supply of oxygen is as important in the combustion of solid carbon as it is in that of the volatile parts of the coal; for it is well known that carbon unites with oxygen in two proportions, forming respectively carbonic oxide and carbonic acid gas.

Carbonic oxide contains . . . . . . 6·12 carbon + 8 oxygen = 14·12.
Carbonic acid contains . . . . . . 6·12 ditto + 16 ditto = 22·12.

To develope the full heat of which carbon is capable, it must receive the double dose of oxygen, and be converted into carbonic acid.

The fact of the generation and escape of large quantities of carbonic oxide from coke fires, especially where the mass of burning fuel is thick, is abundantly proved by experience. If the fire-door of the furnace of a locomotive boiler in full action be opened, a lambent blue flame is at once seen to surround the opening and play over the surface of the fuel, occasioned by the combustion of the carbonic oxide when the fresh air is presented to it. In like manner, a blue flame may occasionally be seen burning at the top of the chimney, the point where, supposing the furnace door to be shut, the heated carbonic oxide first meets a supply of oxygen. If the smoke-box be not quite air-tight, the outer plates have been known to become red-hot by the combustion going on within.

It may be useful to consider what loss of heat may arise as between the conversion of carbon into carbonic acid and of carbon into carbonic oxide. There are no direct means of ascertaining the loss or difference, inasmuch as no direct experiment can be made on the conversion of carbon into carbonic oxide *alone*. We may, however, arrive at a conclusion indirectly in the following way:

According to experiment, cited in the Table (page 4),

| | Units of heat. |
|---|---|
| 1 gramme carbonic oxide, in its conversion into carbonic acid, yields . . . | 2431 |

Consequently

| | |
|---|---|
| 14·12 grammes of carbonic oxide will yield (2431 × 14·12) . . . . | 34325 |

But 14·12 grammes carbonic oxide contain 6·12 grammes of carbon.

Therefore the 6·12 grammes of carbon, during the process of conversion from the state of carbonic oxide to that of carbonic acid, yield 34,325 units, equivalent to

| | Units of heat. |
|---|---|
| 1 gramme carbon, in its conversion from carbonic oxide to carbonic acid, yielding | 5608 |

But according to experiment (see page 3),

| | |
|---|---|
| 1 gramme carbon, in its conversion from carbon into carbonic acid, yields . . | 7900 |

The difference between the two last numbers indicates the heat developed by

| | |
|---|---|
| 1 gramme carbon, in its conversion from carbon to carbonic oxide, . . = | 2292 |

If this reasoning be correct, $\frac{5608}{7900}$ths, or, in round numbers, 70 per cent., of the heat which would be generated in the conversion of carbon to carbonic acid, is lost in the case of the conversion of the same weight of carbon into carbonic oxide only.

Every pound of carbon which escapes through the chimney in the form of carbonic oxide carries off, therefore, as much fuel as would suffice to evaporate 10 lbs. of water from the temperature of 212°.

In the locomotive boiler, the remedy has been partially applied of perforating the fire-door with a number of small holes, and allowing the air to enter through them direct on to the top of the burning coke, from the surface of which the carbonic oxide is rising.

The various sources of waste hitherto detailed, however insignificant they may appear if considered singly, become, when combined together, of serious moment. This was fully evidenced in the saving of full 100 tons of coke per week, effected in the Liverpool and Manchester engines, in the autumn of 1839, in the following manner.

In the autumn of 1838 an account had been opened, against each engine, of the coke delivered, and weekly returns were made up of the general consumption. This served, to a certain extent, as a check, but the result was not so satisfactory as could have been desired. The returns might or might not give accurately the week's consumption. The coke was put loose in the tender, subjected to all the breakage to which its position rendered it liable, and being so placed, no account was taken of the stock remaining at the end of the week.

This might have been greater or less than the stock remaining at the end of the previous week. Hence an error in the week's consumption. Taking a longer period, of course the errors were neutralized, and a correct average obtained; but this was not sufficient. It was necessary to know not merely a month's consumption, nor a week's, but every day's consumption. Nay, it was found important that the drivers should know from hour to hour what they were using. Accordingly the system was changed. The coke, instead of being placed loose in the tenders, was put on in bags, each containing a certain weight, and every night, after the engines had finished work, the remaining ones were counted, and as many fresh ones put on as sufficed to make up a given complement. The driver was not permitted to empty his sacks before he actually wanted to feed his fire, and therefore no waste or breakage could take place. At the same time orders were given to let the fires burn low as the end of the journey was approached, for the purpose of diminishing waste during the intervals of rest.

A table of every week's performance was posted up for the inspection of the men, wherein the engines occupied a higher place in proportion as their consumption was lighter.

These arrangements were carried into effect in October, 1839, and immediately roused an honourable and eager spirit of competition amongst the men.

The records of that period show a marked effect. During the four weeks *preceding* the 19th October, the coke deliveries amounted to 826 tons 9 cwt.; during the four weeks succeeding that day, to only 717 tons 17 cwt., the work done being almost precisely the same.

| Week ending | | | | | | | Tons. | cwts. | qrs. |
|---|---|---|---|---|---|---|---|---|---|
| 28 September, | 1839. | 232 | trips of | 30 miles | + 34½ | days' work | 207 | 4 | 2 |
| 5 October, | „ | 234 | do. | do. | + 34¼ | do. | 203 | 11 | 1 |
| 12 do. | „ | 233 | do. | do. | + 35¼ | do. | 211 | 2 | 1 |
| 19 do. | „ | 236 | do. | do. | + 30¾ | do. | 204 | 11 | 0 |
| | | 935 | do. | do. | + 134¾ | do. | 826 | 9 | 0 |
| 26 October, | 1839. | 233 | trips of | 30 miles | + 35 | days' work | 181 | 8 | 1 |
| 2 Nov. | „ | 233 | do. | do. | + 34¼ | do. | 182 | 3 | 1 |
| 9 do. | „ | 230 | do. | do. | + 34¼ | do. | 174 | 14 | 1 |
| 16 do. | „ | 240 | do. | do. | + 35½ | do. | 179 | 11 | 2 |
| | | 936 | do. | do. | + 139 | do. | 717 | 17 | 1 |

By further practice, and by attending closely to those little defects of which the existence was sure to be indicated by an inspection of the tables, and before any extensive improvements were made in the valves, the quantity was still further reduced, and in February of the following year did not exceed 670 tons.

### THE WORKING DUTY OF STEAM.

The heat necessary to convert a given weight of water of a given temperature into steam has been ascertained to be a constant quantity, independent of the particular pressure and temperature of the steam generated, so that in respect of the duty of fuel it is a matter of indifference whether evaporation is carried on under a high or a low pressure.

A portion of the heat applied to the water is expended in elevating its temperature up to the point at which its conversion into steam of the assigned pressure commences, and the remaining portion is devoted to the conversion of the liquid into vapour, and is essential to its constitution as such.

This heat of conversion (latent heat) diminishes as the pressure and corresponding temperature of the steam increase.

For instance:

| | ℔s. of water. |
|---|---|
| 1 ℔. of water heated from 32° to 212° F. requires as much heat as would elevate through 1° F. . . . . . . . . . . . . . . . | 180 |
| 1 ℔. of water at 212° F. converted into steam at 212° (=14·7 ℔s. per square inch) requires as much heat for its conversion as would elevate through 1° F. . . . | 972 |
| Total . . . . . . . . . . . . . | 1152 |

Again:

| | ℔s. of water. |
|---|---|
| 1 ℔. of water heated from 32° to 329° F. requires as much heat as would elevate through 1° F. | 297 |
| 1 ℔. of water at 329° F. converted into steam at 329° (=100 ℔s. per square inch) requires as much heat for its conversion as would elevate through 1° F. | 855 |
| Total | 1152 |

The number 1152 is, then, a constant which may be taken to express the units of heat contained in 1 ℔. of steam, reckoning from 32° F., the freezing point of water, up to the temperature at which the conversion into steam takes place.

The *mechanical equivalent*, or maximum theoretical duty of this amount of heat, as contained *in* 1 ℔. *of steam*, is

682 ℔s. × 1152 units of heat = 785664 ℔s. *raised* 1 *foot high;*

682 ℔s. through 1 foot being, as before shown, the mechanical equivalent of the unit of heat.

The amount of duty realized in the production and use of 1 ℔. of steam falls, however, far short of this theoretical maximum.

In the earliest stages of the process, those which precede the moment when the water finally assumes the gaseous form, the forces to be encountered before the cohesion of the molecules of the liquid can be overcome absorb and neutralize a large proportion of the effect of the imparted heat.

In fact, the 'heat of conversion' is partly occupied in producing the change of state from liquid to gas, an effect which is unattended by any sensible manifestation of power, and for the remainder consists in producing a pressure or force equal to the tension of the steam on a given area of surface moving through a space which depends on the relative volumes of the water and the steam.

Thus it is obvious that in the most perfect steam engine, acting as it does on the principle of alternate vaporization and condensation, a very considerable amount of the mechanical equivalent of heat is for all practical purposes annihilated; and this reflection may lead to the question whether there may not be discovered some means of reclaiming the lost heat of conversion, and thereby greatly economizing fuel, by the employment of water purely in its gaseous form, subjecting it to such alternations of temperature, *short* of reducing it to the liquid state, as may render it the means of transforming all the heat it receives into a manifested and available equivalent of force.

Owing to the circumstance of the heat of conversion becoming relatively less and less as the pressure increases, the loss or absorption of force is less, the higher the pressure at which the steam is produced.

Making the allowance for this loss, the theoretical work producible from 1 ℔. of steam is in each of the cases here cited as follows:

| | lbs. avoird. raised 1 ft. high by 1 lb. of steam. Theoretical duty. |
|---|---|
| 1st. Low-pressure engine, working inexpansively, and condensing its steam at 112° F. (=1·3 lb. per square inch); the steam formed at 228° F. ( = 20 lbs. per square inch) . . . . . . . . . . . . . | 53,150 |
| 2nd. High-pressure engine, working expansively; steam formed and admitted into cylinder at 284° F. (=51½ lbs. per square inch, or 3 atmospheres), expanding to 104° F. and condensed at 104° F. ( = 1 lb. per square inch) . | 214,734 |

In the first case can only $\frac{1}{14}$th part of the absolute maximum of theoretical duty of the heat imparted to the steam be obtained; in the latter case, about $\frac{2}{7}$ths.

Of this reduced theoretical duty let us see how much has been actually obtained in practice.

1*st case.*—Mr. Josiah Parkes, in his Paper on Steam Engines, records the duty of two condensing inexpansive low-pressure steam engines, viz. an engine at Warwick, with 25-inch cylinder and 5-feet 6-inch stroke, and the engine of the Albion Mills, London, with 34-inch cylinder and 8-feet stroke.

| | |
|---|---|
| The first engine raised . . . . . . . . . | 28,285 lbs. 1 foot high. |
| The second engine raised . . . . . . . . . | 28,489 lbs. „ |
| Mean . . . . . . . . . | 28,387 lbs. raised 1 foot high by 1 lb. of steam. |

This duty is only 53 per cent., or little more than one-half the assigned theoretical duty.

2*nd case.*—The Fowey Consols engine, with 80-inch cylinder, 10-feet 4-inch stroke, cutting off at ¼ stroke, working at a pressure of 40 lbs. per square inch above the atmosphere, has raised

126,359 lbs. 1 foot high by 1 lb. of steam.[11]

This duty amounts to at least 58 per cent. of the assigned theoretical duty. (In the case supposed, the steam would be cut off rather earlier.)

The loss of duty in respect of the steam generated in the boiler may be referred to four general heads, viz.

I. Loss as arising from steam which escapes, either without passing through the cylinders, or if passed through the cylinder, without exerting pressure upon the piston.

II. Loss as arising from resistances against the piston, produced by imperfect action of the valves.

III. An *apparent* loss incidental to the non-condensing engine, as arising from the resistance to the piston afforded by the pressure of the atmosphere.

IV. Loss as arising from imperfect condensation.

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[11] The average duty of all the Cornish engines scarcely exceeds one-half this.

### 1. *Loss from Escapes of Steam.*

Owing to defects of mechanical construction, or to the gradual wear and abrasion of surfaces intended to work upon each other steam-tight, a waste of steam often takes place. This can only be remedied by repairs; but there is another fertile source of waste, which is in great measure under the immediate control of the engine driver,—the loss of steam blown off through the safety-valves when the engine is either standing or working. To give an idea of the loss that may be sustained in this way, the following experiments, made on the Liverpool and Manchester Railway in August, 1839, may be cited.

Four engines in good working order, viz. the 'Rapid' and 'Leopard' passenger engines, and the 'Lion' and 'Mammoth' luggage engines, were selected; and during a day's work of each, as engaged in the ordinary traffic of the line, all particulars of their service were noted down: the time in motion,—the time at rest under steam,—the times of lighting and extinguishing the fires,—the coke delivered throughout the day,—the waste coke thrown aside as useless,—the ashes taken out at night.

The results are condensed into the following Table, the consumption of fuel being reduced to a mileage rate.

| Four trips, 30 miles each, made by each of the following Engines. | Average loads. | HOURS OF WORK. | | | CONSUMPTION OF COKE. | | | | | | | | Con-sumption per hour when at rest. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | In motion. | At rest. | Total. | Whilst in motion. | | During the day, actually burnt or lost. | | During the day, waste excepted. | | During the whole day's work, waste included. | | |
| | | | | | per trip. | per mile. | per trip. | per mile. | per trip. | per mile. | per trip. | per mile. | |
| | | h. m. | h. m. | h. m. | c. q. ℔. | ℔s. | c. q. ℔. | ℔s. | c. q. ℔. | ℔s. | c. q. ℔. | ℔s. | ℔s. |
| Rapid ...... | 10 carriages | 6 21 | 11 19 | 17 40 | 9 0 3 | 33·7 | 10 1 20 | 38·9 | 10 2 24 | 40·0 | 10 3 0 | 40·1 | 67 |
| Leopard .... | 8 ditto | 5 56 | 10 52 | 16 48 | 8 2 25 | 32·6 | 10 2 17 | 39·8 | 10 3 19 | 40·8 | 11 1 0 | 42·0 | 97 |
| Lion ...... | 15 waggons | 7 22 | 9 13 | 16 35 | 10 2 3 | 39·4 | 11 3 10 | 44·2 | 12 0 25 | 45·6 | 12 1 8 | 46·0 | 99 |
| Mammoth .. | 17 ditto | 7 0 | 12 55 | 19 55 | 12 0 25 | 45·6 | 13 2 2 | 50·5 | 14 0 10 | 52·9 | 14 0 14 | 52·7 | 63 |

By this account it is seen, that under circumstances in which more than ordinary care was taken in the working of the engines, the waste of coke going on whilst the engines were at rest averaged about 80 ℔s. per hour; or, calculated upon the mileage, about 7 ℔s. per mile, being an increase of more than one-sixth on the net consumption whilst in motion.

The trial led to a few simple regulations, which resulted in effecting the saving of nearly the entire quantity of fuel consumed whilst the engines were standing. These were as follow: as the engine approached the end of its journey, the fire in the fire-box and the water in the boiler were allowed to run low. Before reaching the station, the feed-pumps were put on and the boiler filled up with water from the tender, the water being of course comparatively cold: after the fire-man had cleaned his bars and picked the tubes, the fire-place was filled up with cold coke: a damper was placed over the mouth of the chimney, and the engine remained in this condition until the time of starting on its next journey. By this time the coke had become ignited throughout; the water had been raised to the boiling point, and if any steam had been generated, it was turned into the tender tank, to warm the feed water. Thus the heat produced during the interval of rest was turned to full account, and made to tell directly upon the work of the succeeding journey.

### II. *Loss from Resistances against the Piston, produced by imperfect Action of the Valves.*

This is a branch of the subject deserving especial consideration. Its importance, as referring to the economical working of steam engines, may be profitably illustrated by a brief historical account of the consecutive alterations and improvements in the valve arrangements and mechanism of the locomotive engines of the Liverpool and Manchester Railway, and of the results produced in the saving of fuel.

It may be premised that the same principles have their application not only to the engines of other railways, making due allowances for difference in the gradients and difference in the loads and dimensions of engines, and difference of speed, but also to fixed engines in general. In fact, they have been applied to the fixed engines of the Liverpool and Manchester with parallel advantageous results.

The history of the Liverpool and Manchester locomotive engines may, for the sake of convenient classification, be divided into two periods: the first a period of increasing, the second a period of decreasing consumption, as respects the article of fuel. Brief allusion may be made to the events of both periods, and a reference to the causes which retarded, as well as to those which accelerated, improvement.

During the first few years after the opening of the railway, the class of improvements comprising the gradual enlargement of dimensions as necessary for maintaining higher rates of speed, and the transport of heavy loads,—the better disposition and proportionment of the component parts, and selection of suitable materials capable of resisting heavy strains, and various other causes of derangement and decay, demanded, in consequence of their direct influence upon the traffic of the Company, unremitting attention. The necessity of securing regularity in the transport of trains, whether of passengers or goods, was pressing and paramount, and afforded sufficient materials for thought and experiment. It is therefore a source of less surprise than regret that little progress should have been made in diminishing the consumption of fuel. Trials of the consumption of different engines of similar size and power, were made from time to time; and these agreeing pretty closely together, served to lull suspicion of unnecessary waste of fuel. As the engines increased in dimensions, the consumption of fuel increased also, which was considered a natural and inevitable consequence of the exertion of increased power.

The adoption, in 1836, for the passenger traffic, of what were termed short-stroked engines, was attended with the establishment of a quicker rate of travelling than had before been known on the line, but unfortunately also with an extravagant increase in consumption of coke. This was erroneously referred to the mechanical disadvantage of the short stroke, an explanation which for a time was deemed satisfactory. Attention was directed to schemes of smoke-burning, by which the use of coal, as a much cheaper fuel than coke, might be rendered possible. In 1836, the 'Liver' was fitted up for burning coal, but proved a failure; and subsequently one or two engines were tried with about equal success. Hitherto all the engines had been furnished with the slide-valve ordinarily used in high-pressure engines, the mode of operation of which is well known to every practical mechanic. It will be remembered, that the operations of admitting the fresh steam and releasing the waste steam are alternately performed by the same valve and by the same motion. The valve being made to slide backwards and forwards upon the face of the ports, opens and closes the several passages in their turn. The two extreme ones, termed steam-ports, communicate with either end of the cylinder. The middle one is termed the exhausting port, and its corresponding passage terminates in a pipe open to the atmosphere and carried into the chimney. Steam is admitted freely into the steam chest from the boiler. The valve is made of sufficient length to cover, when placed in the centre of the stroke, *all* the ports. In this position no steam can enter the cylinder; but as the valve moves on, one of the ports opens, and the arrangement of the valve gearing is such, that when the piston is ready to begin its stroke, the steam-port *begins* to open. During the forward progress of the piston, the valve not only travels to the end of its stroke, but returns to the point from whence it set out. Its continued motion in the same direction finally closes the valve, and prevents any further admission of steam. The steam has now done its work, and must be removed. In the middle of the valve a hollow chamber is formed, of sufficient length to span between the ports. As soon as the edge of this chamber passes the edge of the steam-port, the pent-up steam finds vent, and rushing through the chamber into the exhausting passage, escapes into the chimney.

This is the valve (see Plate II. fig. 1) used on the Liverpool and Manchester Railway until the year 1838, and used in the engines of other lines of railway at that time. Referring to Plate I. figs. 1, 2, 3, 4, 5, it will be observed that the exhausting port opens when the steam-port closes, and both events happen as nearly as may be at the end of the stroke. The perfection of a slide-valve consists, other things being supposed equal, in the degree of nicety with which its motion is *timed*, relatively to the motion of the piston. The functions of the piston are absolutely dependent upon the proper *timing* of the admission and release of the steam. A most slight and apparently trifling error in the adjustment produces a most serious effect upon the consumption of fuel.

If from any cause the valve should open to admit steam for a fresh stroke before the preceding stroke is finished, it opens too soon, and an unnecessary resistance to the piston is produced.

If, on the other hand, the valve should delay its opening until the piston has begun to return, it opens too late, because then the steam has uselessly to fill the space left vacant. Hence a waste of steam and loss of power. As far, then, as the *admission* of steam is concerned, it is a necessary condition that the steam-ports should open neither before nor after, but at the precise moment when the stroke commences. Some engineers indeed have recommended giving the valve '*lead*,' as it is termed, that is to say, setting it so as to open a little before the completion of the foregoing stroke; but it seems very questionable whether the slightest advantage is gained by doing so to a greater extent than is necessary to compensate for any slackness in the parts of the valve gearing, or for their expansion when hot; and about $\frac{1}{16}$th of an inch may be considered sufficient for this purpose in a well-constructed engine.

The valve shown in Plate I. figs. 1, 2, 3, 4, 5, or Plate II. fig. 1, satisfies the conditions required in the *admission* of steam. It opens exactly at the right time. The steam begins to enter as the piston begins to move, and follows it steadily and effectively throughout its course. Whatever time the piston takes for its journey, the steam is allowed as much time to follow it. At first the opening is small, but then the motion of the piston is comparatively slow, and therefore the supply keeps pace with the demand.

As respects the *release* of the steam when the stroke has been completed, the performance of this valve is altogether unsatisfactory, and here lurks the cause of the difference in the performances of the old and the later engines of the Company.

But it might be said, the release *does* appear to take place at the right time, because it occurs just when the piston has finished the stroke, and if it were to occur before, a loss of power would ensue. This is a plausible view of the case, and one which undoubtedly delayed for years the saving of fuel which has since been effected.

Sufficient attention was not bestowed upon the processes going on in the interior of the cylinder, or upon the facts which might have indicated them. Alternately to fill and empty the cylinder of its contents, are operations requiring *time*. The time allowed for the first operation, that of filling the cylinder with steam, necessarily corresponds with the duration of the stroke, whatever its duration may be. But this cannot be the case as regards the second operation, the emptying of the cylinder. This ought to be performed in an instant, in the minutest fraction of the duration of the stroke, otherwise the steam continues pent up when it ought to be liberated,—when it ought to assume its minimum pressure, the pressure of the atmosphere,—and exerts an injurious counter-pressure against the piston, tending to increase the resistance to be overcome.

To effect the free and rapid discharge, it is necessary, not merely to open the communication to the exhausting pipe, but to open a *wide* passage, and to have this *done* by the time the piston recommences its motion. The valve alluded to cannot accomplish this. Its motion is gradual, not instantaneous. The passage only begins to open when the piston is on the turn, and is not wide open until the piston has travelled through one-tenth of its entire stroke. The steam in the cylinder is consequently restrained from escaping, being wire-drawn in the passage out, and consequently takes *considerable time* to assume the pressure of the atmosphere.

In the mean while the new stroke has begun, and been partially completed; and so far the piston has had to contend with a resistance altogether illegitimate,—a resistance which in many cases, and especially at high speeds, has been nearly equal to all the other resistances put together.

In the year 1838, as above mentioned, the extent of the disease was first suspected, and a remedy attempted. It had before been observed that the giving of an engine '*lead*' tended to improve its speed when travelling, already at a high speed, and with a light load. The circumstance was attributed to the opening of the steam-port being wide at the time of commencing the stroke, thereby increasing the facility for the entrance of the steam in following up the piston.

Its true explanation was found to be the earlier release of the waste steam, and consequent diminution of resistance. As sometimes ⅜ths of an inch or even ½ an inch 'lead' was given in passenger engines, it was decided to try the effect of opening the exhausting passage earlier by the same amount, whilst the steam-port should still be made to open only at the turn of the stroke. An engine called the 'Lightning' was chosen for the experiment. Its original valve resembled fig. 1, Plate II.;—placing the valve on the ports, so as to allow the exhausting passage to be ⅜ths of an inch open, the steam-port would at the same time be ¼ inch open. This space therefore was closed by adding to the length of the valve at each end ¼ inch. The eccentric was of course shifted on the axle to correspond with the alteration, and the engine with the altered valve (see fig. 2, Plate II.) was again set to work in March, 1838. The amount by which the valve at each end overlaps the steam-ports, when placed exactly over them, is technically termed the '*lap*.' The lap of the 'Lightning's' valve being then ⅜ths of an inch, the exhausting passage was about ⅜ths of an inch open when the stroke was finished. This engine was made the subject of several experiments. With coach trains, the saving in fuel was very considerable; the consumption, whilst running, being only about 25 lbs. per mile with loads of five to eight coaches, and the speed was considerably improved.

It here becomes necessary to refer to the consumption of the Liverpool and Manchester engines before and at the time we speak of, in order to form a just conception of the position arrived at.

The amended performance of the 'Lightning' was little better than the best performances at the end of the year 1830. The 'North Star,' 'Phœnix,' 'Arrow' and 'Meteor,' engines of that period, when in first-rate condition, and expressly put upon trial, consumed about 25 lbs. per mile; but this was with loads of only four carriages, and at a very inferior speed.

Again, in June, 1832, the 'Victory' and 'Planet' were burning about 30 lbs. per mile, with coach trains. In 1833, the 'Sun' and 'Etna' used about 28 lbs. per mile. This is their consumption when actually running, *i. e.* their net consumption.

The experiments of M. De Pambour, in 1834, were carefully conducted, and may be fully relied upon. In his 'Treatise on Locomotive Engines,' (2nd edition, page 312, 1840,) he gives a table, by which it appears that the best performances of the best engines, as the 'Jupiter,' was 26·3 lbs. coke per mile, with 8 coaches, at 24·58 miles per hour; and the best performance of luggage engines, 38 lbs., with 25 waggons (= 120 tons), at 17 miles per hour. This was their net consumption. The distinction between the total amount of fuel consumed by any engine, and the fuel it consumes when actually running, must be carefully borne in mind. It will be marked by the terms *net* and gross consumption. Coke must be burnt in raising the steam, and afterwards in keeping it up during the intervals of rest, which therefore enters into the gross, but not into the net consumption.

In 1836 and 1837, larger engines were gradually introduced, to replace the smaller class, which had become insufficient for maintaining the higher rate of speed then demanded; and their increased consumption of fuel was commensurate with their increase of size.

For an idea of the general effect attendant upon their introduction, the following table, showing the coke consumed in several consecutive years, may be consulted:

11,561 trips in 1835 = 7907 tons coke gross.
12,063 „ 1836 = 9876 „ „
12,953 „ 1837 = 10816 „ „

Thus, during three years when the change went on, although the work done increased only in the proportion of 100 to 112, the consumption of fuel increased in the proportion of 100 to 136, without any material difference in the magnitude of the loads.

In 1838 and 1839, the average consumption attained its maximum, being about 49 lbs. per mile gross with passenger trains averaging seven coaches, and 54 lbs. per mile with luggage trains averaging sixteen waggons.

Forty pounds *net* consumption, with coach trains, was moderate for such an engine as the 'Lightning;' and the performance of the 'Lightning,' when altered, being under 30 lbs. net, was naturally considered favourable. This result was evidently obtained from the earlier exhaustion of the steam.

Whereas previously the opening of the exhaustion passage was contemporaneous with the termination of the stroke, now it took place before, and was already ⅜ths of an inch open at the end of the stroke. A portion of the steam could by that time escape, and the back pressure was diminished.

The valves of two engines, called the 'Rapid' and 'Arrow,' were next altered, to have ⅜ths of an inch lap; the 'Rapid' in January, the 'Arrow' in June, 1839. During the last quarter of the year 1839, the *gross* consumption of the 'Rapid' was 36½ lbs. per mile; and that of the 'Arrow' 40 lbs. per mile; and the net consumption probably about 30 and 33 lbs.

ARROW.—*Valve with ⅜ths of an inch lap.*

| Week ending | | Coke. cwt. | qrs. | lbs. | | per trip. cwt. | qrs. | lbs. | | per mile. lbs. |
|---|---|---|---|---|---|---|---|---|---|---|
| January 4, 1840, | 12 trips of 30 miles, | 130 | 0 | 0 | | | | | | |
| „ 11, „ | 12 „ „ | 127 | 2 | 0 | | | | | | |
| | 24 | 257 | 2 | 0 | = | 10 | 2 | 25 | = | 40·1 |

*Valve with ¾ths of an inch lap.*

| | | cwt. | qrs. | lbs. | | cwt. | qrs. | lbs. | | lbs. |
|---|---|---|---|---|---|---|---|---|---|---|
| February 9, 1840, | 10 trips of 30 miles, | 88 | 3 | 0 | | | | | | |
| March 7, „ | 8 „ „ | 71 | 1 | 0 | | | | | | |
| „ 21, „ | 14 „ „ | 118 | 3 | 0 | | | | | | |
| „ 28, „ | 16 „ „ | 137 | 2 | 0 | | | | | | |
| | 48 trips, | 416 | 1 | 0 | = | 8 | 2 | 19 | = | 32·4 |
| | | | | | | | | | Difference | 7·7 |

Here was a confirmation of the principle first recognized in the case of the 'Lightning;' and it became a question how far this principle might be advantageously carried out, and whether the exhaustion might not be made to take place still earlier. This could not be accomplished without, at the same time, cutting off the steam earlier; or, in other words, by virtually shortening the stroke. The fear of impairing the power of the engine at first deterred from venturing the experiment; but at length a trial was made in the 'Arrow,' whose valve was altered to have ¾ths of an inch instead of ⅜ths of an inch lap at each end. (See fig. 3, Plate II.) Since the travel of the valve remained as before, the valves did not open quite full port, but only ⅞ths of an inch. In February, 1840, the alteration was effected, and an immediate reduction of nearly 8 lbs. per mile was the result. The gross consumption of this engine with coach trains was 40·1 lbs. before the alteration; it was only 32·4 lbs. after it. A saving of 20 per cent. had been effected: at the same time, no injurious effect was observed upon the power, but rather the reverse.

An invention, which was made a little before the time we now speak of, tended more completely than any thing had hitherto done to show the impossibility of fixing any ultimate determinate standard of consumption, and consequently gave a considerable impulse to the further improvement of the engines. This was the patent expansive valve gearing of Mr. John Gray, as applied to the 'Cyclops,' an engine of the same dimensions and make as the 'Lightning.'

This engine underwent a thorough repair in the summer of 1839; and in October, soon after it came out, was made the subject of an extensive series of experiments.

The alteration consisted in the adaptation of particular mechanism for working the valves, whereby the engine-man was enabled, without disturbing the regulator, to vary at pleasure the quantity of steam admitted into the cylinder within the limits of a range extending from 46 to 82 per cent. of the length of the stroke, allowing the steam to act expansively after being cut off.

The advantages proposed to be attained by the arrangement were, to accommodate the power of the engine to the load to be conveyed, and to the inclinations of the road; to establish, in fact, a property of adjustment, by the aid of which an engine, constructed for the transport of very heavy loads, might be adapted to the exigencies of an irregular and uncertain traffic, without entailing any unnecessary expenditure of fuel.

The conclusion arrived at upon completing the experiments was, that a saving of at least 12 per cent. in fuel over the best engines had been effected by the application of the new gearing, without occasioning any diminution in the speed of travelling.

Its net consumption was 22½ lbs. per mile; its gross consumption 28½ lbs. per mile, with loads of seven coaches.

This, though little better than the performance of the 'Arrow,' in March, 1840, was, it will be remembered, accomplished four or five months before, and was in fact the cause of a keener prosecution of the trials with different valves.

Whether or not the favourable results of the 'Cyclops' were actually due to using steam expansively, is a point upon which engineers may not perhaps be agreed; but the subsequent history of the locomotive engine has made it apparent that the expansive action only partially contributed to the success of the experiment.

In Mr. Gray's apparatus, the time of closing the steam-port was made to vary by altering the length of the travel of the valve, and a simultaneous adjustment of the position of the valve on the ports took place to suit the altered travel, making the valve still to open at the right time. The old valve would not have been applicable, nor have fulfilled the specified conditions; for, bearing in mind that in any case the steam-port is to open when the stroke of the piston commences, and that the old valve was scarcely longer than was just sufficient to cover both steam-ports, it is evident that an alteration merely in the *travel* of the valve would not have allowed the steam to act expansively, since the steam can only so act when *both* steam-ports are closed; that is, whilst the valve is travelling through a space equal to the length of the external lap, plus that of the internal ( = ⅞ inch + ⅜ inch = 1¼ inch in the case of the 'Cyclops'). Therefore *lap* was given to the valve both internally and externally; *internally*, to delay the opening of the exhausting passage; externally, that *time* might intervene between the operations of exhausting the waste and admitting the fresh steam. (See fig. 4, Plate II.)

And inasmuch as the external lap exceeded the internal, by so much the arrangement resembled, and in fact partook of the principle of the valves of the 'Rapid' and 'Arrow,' the result of their difference being, that the exhausting passage was half an inch open at the end of the stroke.

To this principle, viz. the earlier exhaustion of the waste steam, and to the higher pressure of steam in the boiler, may be ascribed the improvement in the 'Cyclops.' Whatever benefit may have been derived from expansive working was, to a considerable extent, neutralized by the compression of the waste steam left in the cylinder after the closing of the exhaustion passage, an evil which increased in proportion as the steam was cut off earlier.

The next important improvement in the valves is due to Mr. Dewrance, and was suggested by him early in the year 1840. His principle was, that the exhausting passage, instead of being only partially open at the moment of completing the stroke, as was more or less the case with the engines before named, should be nearly wide open, which was to be accomplished by making the 'lap' of the valve equal to the width of the steam-port. Moreover, that the travel of the valve should be made proportionate to the increased lap, so as to allow the same area or the same amount of opening of the steam-port for the admission of steam. This latter condition was not fully obtained in the instances of the 'Lightning,' 'Arrow,' and 'Rapid.' It would at least have involved the sacrifice either of the eccentrics or other parts of the valve gearing, in order to obtain the additional travel of the valve, and perhaps might have been altogether impossible from want of room in the steam chest itself. Therefore in those engines, after being altered, the valves did not open so wide as before.

A favourable opportunity now occurred for carrying out these ideas, both as regarded increased lap and increased travel, from the circumstance of two engines requiring extensive repairs, which would allow time for the needful alterations.

One inch lap was given to the 'Rapid's valve, which was now made to travel 4¼ inches. (See fig. 5, Plate II.) The result of this arrangement was, that the exhausting passage was one inch open at the end of the stroke, and that supposing the stroke of the piston divided into 100 equal parts, the steam was cut off at 79; it expanded from 79 to 95; at 95 it began to be released, and was escaping into the atmosphere from 95 to 100. The operation of this valve is shown in figs. 6, 7, 8, 9, 10, Plate I.

The 'Rapid's *gross* average consumption of coke, when running sixty-four trips of thirty miles each with coach trains, *before* the alteration, was 36·3 ℔s. per mile; and 28·6 ℔s. per mile immediately *after* the alteration.

Thus we have a measure of the effect produced—a saving of one-fourth of the fuel.

It had become a question whether the Company should not proceed to adapt the expansive gearing to more of their engines; but an engine having now been made to rival the 'Cyclops,' without in any degree increasing the complexity of the gearing, it was considered more desirable to delay proceedings until the simpler method was fully tested by numerous experiments.

To accomplish this in the then existing engines was found to be no easy task; for on examination it was discovered that, in many cases, there was no room in the steam chest for valves of greater lap; in others, that it was impossible to increase the length of travel. Therefore it was necessary to prepare, in the first instance, for the sacrifice of at least the cylinders, steam chests, working gear, and inside framing of several engines then needing repair, and eventually, as resources would permit, for replacing the Company's entire stock with new engines, all built according to one model, combining the latest improvements experience had shown worthy of introduction, trusting that the saving in fuel, and in the general expenses of repairs, would speedily repay the Company for the immediate sacrifice. These views fortunately proved to be well founded. The loss was soon recovered; for the saving in the cost of fuel and repairs considerably exceeded the outlay, and although during the years 1840, 1841, 1842, the Company turned out from their workshops twenty-four new engines, (the cost of the whole being debited to current disbursements, under the head of 'Locomotive Power,') and broke up as many old ones, yet at the same time the total expenses of the locomotive department underwent a gradual reduction from £51,580 per annum, the charge in 1839, to £25,732, the charge in 1842.

Some engines, such as the 'Vesta,' 'Swiftsure,' 'Phœnix,' 'Etna,' 'Rokeby,' 'Meteor,' and 'Sun,' were altered at a trifling expense, so as to approximate towards the improved principle, and thus tended to keep down the consumption of coke whilst more perfect engines were in course of formation.

The 'York' was several months under repair, and did not come into action until 1841.

Finally, all the engines belonging to the Company were furnished with the improved valve, (see fig. 5, Plate II.,) answering to the 'Rapid's, the lap being 1 inch, the travel 4 inches, the ports 1⅛ inch wide. In casting new cylinders, great care was of course taken to enlarge the area of the passages of exhaustion, most of the older engines having been too much contracted at this part. Attention to this point exercised a further beneficial effect in saving fuel.

Every step towards increasing the 'lap' was thus found to conduce to the good working of the engine. The waste steam was no longer choked up in the cylinder; its prejudicial resistance was removed, and, in consequence, a much less quantity of steam and fuel sufficed to do the same useful work. As a further consequence, the area of the blast-pipe could be enlarged without risk of a deficiency of steam, the coke was no longer chafed by the violence of the draft, and the fire-bars could be placed closer together, to diminish the loss of fuel dropping between them.

Having considered the effects of the old and the new valve with reference to the motion of the piston, it may be interesting also to compare the times allowed in either case for the performance of the function of releasing the steam, as by so doing we may gain a clearer conception of the difference subsisting between them.

Supposing the velocity of the engine to be uniform, the angular velocity of the crank is uniform also. Half a revolution of the crank, equal to 180°, corresponds with one stroke of the piston. Let us assume the stroke, or, which is the same thing, a half-revolution of the crank, to be accomplished in a unit of time.

We shall find, as a matter of fact, from the known relative motion of the crank and piston-rod, that the angular motion of the crank from the initial or dead point has been as follows, up to the moment when the exhaustion passage begins to open, the valve being set without lead.

| | Angular motion of crank from dead point. | Remaining to be passed over. |
|---|---|---|
| Valve with 0 inch lap | 0° to 180° | 0° |
| ,, $\frac{3}{8}$ ,, | 0° to 165° | 15° |
| ,, $\frac{3}{4}$ ,, | 0° to 158° | 22° |
| ,, 1 ,, | 0° to 153° | 27° |

Therefore the times are as

| | | |
|---|---|---|
| $\frac{0}{180}$ | corresponding with | old valve, |
| $\frac{15}{180}$ | ,, | Lightning's, |
| $\frac{22}{180}$ | ,, | Arrow's, |
| $\frac{27}{180}$ | ,, | new valve, |

or as the numbers 0, 15, 22, 27, which represent the *relative* times allowed for performing the release of the steam by the four different valves.

There is of course a limit to the application of this principle. The time gained for exhaustion is time lost, as regards the application of the power of the steam: in other words, the sooner we begin to exhaust, the sooner we must cut off the steam; the more we must reduce the length of the effective stroke.

Finally, a point is arrived at where the loss of power from earlier cutting off is equalled by the illegitimate resistance of back pressure removed, and up to this point we cannot do wrong in going; for then, without impairing the useful power of the engine, we are saving all the fuel necessary to overcome what would otherwise be back pressure. In practice it is found, that under an equal pressure of steam the one-inch lap does not impair, but rather improves the tractive power of an engine when travelling with a maximum load, and much more, therefore, with any load short of the maximum.

### III. *Loss from Resistance of Atmosphere against the Piston.*

This is a loss incidental to all forms of the non-condensing engine; but its amount varies relatively to the useful effect produced, according to circumstances over which the engineer has in some measure a control, and it rests with him so to proportion the dimensions of the cylinder and the speed of the piston to the resistance required to be overcome, as to render the loss the least possible.

After the exhausting passage has been fully opened, and before the piston begins its stroke anew, the cylinder, being now open to the atmosphere, is filled with steam equal, at least, to the pressure of the atmosphere; which pressure therefore has now to be driven before the piston. The quantity of steam expended in neutralizing the pressure of the atmosphere for one stroke of the piston is a volume equal to the contents of the cylinder at a density corresponding with the pressure of 14·7 lbs. per square inch; and the volume of water necessary for producing it is equal to $\frac{1}{1700}$th part of the volume of such steam.

The evaporating power of any given boiler being limited, it is easy to see that the area of the piston and velocity of its motion must bear a direct reference to the rate of evaporation; for otherwise a result ranging between the two following extreme cases may occur: either the volume measured out by the pistons in a given time may be smaller than the boiler is competent to fill with steam of the requisite density,—in which case the pressure in the boiler will increase, and the excess of steam will escape through the safety-valves,—or the volume measured out by the pistons in a given time may be so great as to reduce the pressure until it scarcely exceeds that of the atmosphere; in which case the force of the steam generated is nearly wholly absorbed in overcoming the atmospheric pressure on the pistons.

In fixed engines, working as they generally do under nearly constant loads at nearly uniform velocities, the relation between useful effect obtained and the work expended in neutralizing the pressure of the atmosphere seldom varies, at least not sufficiently so to attract attention; but in locomotive engines the tendencies towards the above-mentioned extremes are more strongly marked, in consequence of the great variation in load and speed to which they are constantly subject.

In any non-condensing engine we may conceive the duty of the water evaporated, and therefore of the fuel which produces the evaporation, taken irrespective of waste, as divided into two parts; one of which is constant for equal spaces traversed by the piston or by the engine, the other variable and dependent upon the load.

If we take as an example the Liverpool and Manchester passenger engine of 1840 to 1845, with 12-inch cylinders, 18-inch stroke, and 5-ft. wheels, and take one mile as the unit of distance traversed, we find the volume of steam expelled to be

336 revolutions × 4 cylinders full × 1·162 cube feet = 1562 cube feet per mile.

With the ordinary loads of say seven or eight coaches, about 15 lbs. of coke are consumed and (15 × 7½) 112 lbs. of water. 112 lbs. of water converted into 1562 cube feet of steam has its volume increased 869 times, which answers to a pressure of 30·5 lbs. per square inch as the average total force applied to the piston. Of this total force 14·7 lbs. are expended in neutralizing atmospheric pressure, and the remainder only to overcoming the external resistances of the engine and train. Here loss from pressure of the atmosphere is as great as the useful effect.

Apply the same engine to the conveyance of a heavier load, say a luggage train of 100 tons: the consumption of water now becomes 150 lbs. per mile instead of 112 lbs. as before, with the lighter load; but the steam used in overcoming atmospheric pressure is the same.

The relation between the total work of the steam and the useful effect has therefore changed from the ratio of

100 : 50 in the 1st case, to that of
100 : 62 in the 2nd case.

Suppose the area of the cylinders of the same engine reduced to *half* their original size, all other parts remaining the same, but the working pressure increased to make up for the reduction of area; then the loads being as before, the relation of total work to useful work will be as the ratios

100 : 74 in the 1st case,
100 : 80 in the 2nd case,

which is equivalent to a gain of about 20 per cent.; or if we suppose the area of the cylinders to be *doubled*, the ratios would become as

100 : 0 in the 1st case,

indicating that no useful effect is obtained, and that the whole of the steam is applied to the neutralizing atmospheric pressure, and as

100 : 24 in the 2nd case.

The practical considerations which limit and determine the proper proportions of the cylinder and wheels are chiefly these:

1st, The most convenient maximum working pressure, having due regard to safety.
2nd, The maximum resistance to be encountered by the engine, say at starting or at any stage of its journey.
3rd, The surplus power in excess of maximum resistance, as necessary for obtaining a sufficiently rapid acceleration of speed after starting a train.

The evaporating power of the boiler must necessarily be a function of the speed to be maintained under the conditions of the average resistance.

In engines of different proportions, the 'constant' consumption of water and fuel will vary directly as the square of the diameter of the cylinder, directly as the length of stroke, and inversely as the diameter of the driving wheels: in other words, it will be proportional to the volumes of steam measured off by the cylinders in traversing the same unit of distance.

Computing the 'constant' consumption for three sizes of engine, viz.

| | |
|---|---|
| No. 1. The Liverpool and Manchester passenger engine, above referred to, . . . . . . . | 12″ cylinder, 18″ stroke, 5-ft. wheels, |
| No. 2. The larger and standard size now made for trains running between Liverpool, Birmingham, and Manchester, | 15″ cylinder, 20″ stroke, 6-ft. wheels, |
| No. 3. The Great Western Railway passenger engine, 'Great Britain,' . . . . . . . | 18″ cylinder, 24″ stroke, 8-ft. wheels, |

we have

| | | | | | | |
|---|---|---|---|---|---|---|
| No. 1 | consuming | 57·26 lbs. | of water per mile, | and | 7·63 lbs. | of coke per mile, |
| No. 2 | „ | 82·83 | „ | „ | 11·04 | „ |
| No. 3 | „ | 107·36 | „ | „ | 14·31 | „ |

(allowing 7½ lbs.[12] water to 1 lb. coke,) before any effective work can be obtained from the steam.

It would be impossible to prescribe any general solution of the problem of the proportions of the cylinders and driving wheels of engines, seeing that very various and complicated considerations are involved, referring to conditions imposed by the nature and amount of the traffic; as, for example, the extent to which it must be subdivided into individual trains,—the speed at which it has to be conveyed,—the gradients of the railway. Nevertheless it may be borne in mind that the greater the pressure at which the steam is made to act in the cylinders, and the smaller the volume of steam emitted on the journey, the greater will be the saving in fuel.

Generally speaking, the pressure of steam in the cylinder is much below the pressure in the boiler when the engine is travelling at a high speed.

On starting a train, or for enabling it to surmount an occasional steep inclination, it is most desirable to have large cylinders, to gain the requisite amount of power; but when the speed has been attained, or the incline surmounted, the force is reduced, the steam becomes attenuated in the cylinders, and the large cylinders are the direct occasion of waste of fuel, and in fact prevent the attainment of as high a velocity as would result under the same circumstances, were the cylinders smaller.

The contrivance of some easy method of varying the power of an engine whilst in motion is still a desideratum.

In one way indeed this is already in many instances done by cutting off the steam at different points of the stroke, and working expansively; but considering the comparatively low average pressure which the steam assumes in the cylinder at high speeds, and that it cannot be allowed to expand *below* the pressure of the atmosphere,—also that the last atmosphere remaining in the cylinder has not taken any part in the 'effective' duty of the engine, but is, so to speak, thrown away, whether the engine is worked expansively or not,—it seems very doubtful in theory, and the results of practice would seem to confirm this view, whether any real advantage is gained by the so-called expansive working.

---

[12] *i.e.* 7½ lbs. of water evaporated from say 50° F.

Some simple and inexpensive means of effecting a condensation of the *last* remaining atmosphere of steam, reserving the excess above one atmosphere for producing the blast, combined with the means of working expansively, would effect all that is desired, and at the same time permit a reduction in the size and weight of the boiler and engine.

### IV. *Loss as arising from imperfect Condensation, and from Heat carried off by, and not recovered from, the condensing Water.*

In the condensing engine, the heat abstracted from the steam is imparted to the injection water, and to the water surrounding the condenser, and the temperature of the condensing water is elevated. The resistance to the piston, per unit of surface, after condensation has taken place, is equal to the tension of saturated steam, as answering to the final temperature of the injection water.

| | | | | |
|---|---|---|---|---|
| At a temperature | 60° F. | the force of vapour is | 0·26 ℔. | per square inch. |
| „ | 80° F. | „ „ | 0·50 ℔. | „ |
| „ | 100° F. | „ „ | 0·93 ℔. | „ |
| „ | 120° F. | „ „ | 1·65 ℔. | „ |
| „ | 140° F. | „ „ | 2·88 ℔. | „ |

In condensing a given weight of steam, the greater the quantity and the lower the temperature of the injection water used, the less will be the tension of vapour, and consequent counter-pressure.

In practice, a final temperature of 120° F. in the injection water = 1·65 ℔. pressure per square inch, may be considered an average result. Suppose the initial temperature to be 52°, the quantity of injection water admitted must be at least 16 times the weight of steam condensed; for

| | Units of heat. |
|---|---|
| In 1 ℔. of steam there exists, as measured above the freezing point (32° F.), . | 1152 |
| From this deduct 120°— 32 . . . . . . . . . . . . | 88 |
| The difference is the number of units of heat abstracted from the steam to reduce it to water and vapour at the final temperature of 120° F. = . . . . . | 1064 |

To every pound of the cold injection water (120° — 52° = ) 68 units of heat are added; consequently 1064 ÷ 68 = 15·6 ℔s., the weight of water required to condense 1 ℔. of steam, about $\frac{1}{16}$th part of the heat imparted to the injection water, when pumped out of the condenser, is restored to the service of the engine: the remaining $\frac{15}{16}$ths go to waste.

It has been ingeniously proposed in a recent patent, that of Mr. Siemens, to obviate much of this loss by employing a peculiar form of condenser and arrangement of the valves, by which the steam issuing from the cylinder shall be presented in successive portions to a range of compartments in the condenser, in such order that the hottest steam comes in contact with the hottest condensing water; the next portion in contact with cooler water, and so on, until the last expansion is condensed with water of the temperature at which it can be obtained; a series of operations which, although strictly consecutive, may be conceived as being practically simultaneous. The injection water entering the condenser at a temperature of 52° would issue from it at the boiling point, and be pumped from thence into the boiler at a temperature 92° higher than it attains in the usual manner, effecting a corresponding saving of fuel, besides accomplishing a more perfect condensation. With the aid of such an apparatus, it has been also suggested to render the present non-condensing engine partially condensing by the use of a very limited supply of condensing water, allowing part of the steam to escape in the usual way through the eduction or blast-pipe, and to condense only the remaining volume of steam as at, or below, the atmospheric pressure.

The injection water entering at 52° and issuing at 212°, would carry off from the steam 160 units of heat. Those portions of the steam which condense at 52°, or at other temperatures *below* 212°, act the part of *condensing water* in the successive compartments of the condenser, until finally the condensed steam issues from the last compartment at 212°. Consequently the condensed steam merely gives up its latent heat, 972 units (1152° — 180°), and the proportion of condensing water to steam would be as 972 : 160, or as about 6 : 1.

Reverting, for the sake of illustrating the general case of a non-condensing engine, to the case of the locomotive with 12-inch cylinder, 18-inch stroke, and 5-ft. wheels, we have seen that the weight of steam passing through the cylinders per mile for neutralizing atmospheric pressure was 57·26 lbs. To condense this (57·26 × 6 = 344 lbs. or) 35 gallons of water per mile would be required. Supposing the engine to be working with a load equivalent to a *total* pressure of four atmospheres on the pistons, the water evaporated to supply steam of that pressure would be, exclusive of waste, (1562 cubic feet of steam divided by 474, the relative volume of steam at that pressure to its producing water, = 3·3 cube feet, or) about 20 gallons per mile. The boiler would be supplied with 20 gallons per mile (plus whatever might supply waste) from the water at boiling point derived from the condenser, and the remaining 15 gallons (or less) of heated water would go to waste. If such an additional supply of water could be maintained without inconvenience, the advantages resulting would be —

1st, An increase of effective power in the engine in the ratio of 3 atmospheres to 4 atmospheres, for the *same* quantity of water evaporated or fuel used, irrespective of any benefit from expansive working.

2ndly, The opportunity of working the steam expansively to a greater extent than has hitherto been practicable.

3rdly, That the boiler is fed with hot water.

Having considered in some detail the circumstances which influence the working duty of fuel in respect of the production of steam, and the working duty of steam in respect of the production of force, it may be well to present a general summary of the results already noticed, so as to exhibit at one view the aggregate influence of all the causes which combined to diminish the consumption of fuel in the Liverpool and Manchester engines.

In the first Table annexed, the performances of the various engines mentioned are shown.

In the second Table, the progressive reduction in consumption of fuel is noted, with a brief explanation of the causes.

## TABLE I.

| Date. | Engines. | Observations. | Gross Consumption. | Net Consumption. | |
|---|---|---|---|---|---|
| | | | lbs. ℔ mile. | lbs. ℔ mile. | |
| 1830. | North Star.. | Loads of 4 carriages .. | ...... | 25·0 | |
| | Phœnix .... | | | | |
| | Arrow...... | | | | |
| | Meteor .... | | | | |
| 1832. | Victory .... | Ditto .............. | ...... | 30·0 | |
| | Planet...... | | | | |
| 1833. | Sun........ | Ditto .............. | ...... | 28·0 | |
| | Etna ...... | | | | |
| 1834. | Jupiter ..... | Load of 8 carriages. | | | |
| 1838. | Average of all coaching engines .... | | 49·0 | 40·0 | Loads of 7 carriages. |
| March | Lightning .. | ⅜-inch lap to valve.... | ...... | 25·0 | |
| 1839. Nov. | Rapid ...... | ⅝-inch ditto .... | 36·3 | 30·0 | |
| Nov. | Arrow...... | ⅜-inch ditto .... | 40·1 | 33·0 | |
| Nov. | Cyclops .... | Gray's patent gearing . | 28·5 | 22·5 | |
| 1840. | Arrow...... | ¾-inch lap to valve.... | 32·4 | | |
| | Rapid ...... | 1-inch ditto...... | 28·6 | | |

## TABLE II.

| | Gross consumption of coke per mile. |
|---|---|
| Average consumption of the Company's engines in the summer of 1839. Old valve . . . . . . . . . . . . . | 49 lbs. |
| Average consumption of the Company's engines after the introduction of new mode of coke deliveries. Old valve . . . . . . . | 40 lbs. |
| Valves with ⅝ths of an inch lap . . . . . . . . . | 36 lbs. |

## TABLE II. (*continued.*)

| | Gross consumption of coke per mile. |
|---|---|
| Valves with ¾ths of an inch lap . . . . . . . . . . | 32 ℔s. |
| Valves with 1-inch lap, as applied to the old steam and exhausting passages, . | 28 ℔s. |
| Same valves and same engines, but with increased care in firing, so as to avoid all unnecessary waste of fuel, . . . . . . . . . | 22 ℔s. |
| Valves with 1-inch lap, as applied to new engines with enlarged exhausting passages, larger tubes, and closer fire-bars, and greater accuracy of construction, . . . . . . . . . . . . . . | 15 ℔s. |

The following Tables give a general summary of the work done, coke consumed, and loads conveyed by the several classes of engines, for four years.

## TABLE III.

### GROSS CONSUMPTION OF COKE.

| | PASSENGER ENGINES. | | COKE. | | | |
|---|---|---|---|---|---|---|
| | | | Tons. | cwt. | qrs. ℔s. ꝑ mile. | |
| Half-year ending June, 1840 | . . 3463 trips, 30 miles, | | 1523 | 16 | 3 = 32·9 | Average loads, 7 coaches. |
| December, ,, | . . 3596 | ,, ,, | 1276 | 9 | 1 = 26·5 | |
| June, 1841 | . . 3493 | ,, ,, | 1036 | 15 | 3 = 22·1 | |
| December, ,, | . . 3496 | ,, ,, | 958 | 19 | 0 = 20·5 | |
| June, 1842 | . . 3655 | ,, ,, | 853 | 3 | 3 = 17·4 | |
| December, ,, | . . 3526 | ,, ,, | 684 | 9 | 2 = 14·5 | |
| June, 1843 | . . 3243 | ,, ,, | 646 | 1 | 1 = 14·9 | |
| December, ,, | . . 3555 | ,, ,, | 717 | 2 | 2 = 15·1 | |
| June, 1844 | . . 3455 | ,, ,, | 722 | 18 | 3 = 15·6 | |
| December, ,, | . . 3786 | ,, ,, | 901 | 6 | 1 = 17·8 | |
| June, 1845 | . . 5338 | ,, ,, | 1292 | 15 | 0 = 18·1 | |

| | LUGGAGE ENGINES. | | | | | |
|---|---|---|---|---|---|---|
| Half-year ending June, 1840 | . . 1925 trips, 30 miles, | | 1160 | 12 | 3 = 45·0 | Average loads, 22 waggons, = 110 tons gross, exclusive of engine and tender. |
| December, ,, | . . 1653 | ,, ,, | 867 | 9 | 3 = 39·2 | |
| June, 1841 | . . 1640 | ,, ,, | 749 | 0 | 1 = 34·1 | |
| December, ,, | . . 1370 | ,, ,, | 531 | 17 | 1 = 29·0 | |
| June, 1842 | . . 1604 | ,, ,, | 559 | 2 | 2 = 26·0 | |
| December, ,, | . . 1521 | ,, ,, | 421 | 17 | 2 = 20·7 | |
| June, 1843 | . . 1588 | ,, ,, | 441 | 7 | 2 = 20·7 | |
| December, ,, | . . 1605 | ,, ,, | 451 | 12 | 2 = 21·0 | |
| June, 1844 | . . 1576 | ,, ,, | 492 | 12 | 2 = 23·3 | |
| December, ,, | . . 1630 | ,, ,, | 539 | 1 | 1 = 24·7 | |
| June, 1845 | . . 1799 | ,, ,, | 596 | 6 | 1 = 24·7 | |

## TABLE III. (*continued.*)

BANK ENGINES.

| | | | COKE. | | |
|---|---|---|---|---|---|
| | | | Tons. | cwt. | qrs. |
| Half-year ending June, | 1840 . . | 349 days, | 486 | 11 | 3 |
| December, | „ . . | 356¼ „ | 369 | 10 | 0 |
| June, | 1841 . . | 349½ „ | 343 | 3 | 2 |
| December, | „ . . | 341¾ „ | 251 | 11 | 0 |
| June, | 1842 . . | 361 „ | 174 | 6 | 3 |
| December, | „ . . | 363½ „ | 143 | 13 | 3 |
| June, | 1843 . . | 452¼ „ | 162 | 8 | 3 |
| December, | „ . . | 517¾ „ | 183 | 12 | 2 |
| June, | 1844 . . | 453 „ | 183 | 5 | 0 |
| December, | „ . . | 485 „ | 219 | 12 | 2 |
| June, | 1845 . . | 477 „ | 210 | 16 | 1 |

COAL AND BALLAST ENGINES.

| | | | | | | |
|---|---|---|---|---|---|---|
| Half-year ending June, | 1840 . . | 436¼ days, | 489 | 4 | 0 | Average load, 15 waggons. |
| December, | „ . . | 370 „ | 344 | 17 | 3 | |
| June, | 1841 . . | 334 „ | 325 | 4 | 2 | |
| December, | „ . . | 351¾ „ | 312 | 4 | 2 | |
| June, | 1842 . . | 407 „ | 313 | 3 | 2 | |
| December, | „ . . | 443¾ „ | 243 | 3 | 3 | |
| June, | 1843 . . | 306½ „ | 226 | 5 | 0 | |
| December, | „ . . | 398¼ „ | 274 | 13 | 0 | |
| June, | 1844 . . | 386 „ | 276 | 18 | 3 | |
| December, | „ . . | 639 „ | 484 | 2 | 2 | |
| June, | 1845 . . | 776 „ | 660 | 11 | 1 | |

## TABLE IV.

GENERAL RESULT.

| | | |
|---|---|---|
| In the year 1838 . . . | 12604 tons of coke consumed, | |
| 1839 . . . | 11754 „ „ | |
| 1840 . . . | 6518 „ „ | |
| 1841 . . . | 4508 „ „ | |
| 1842 . . . | 3393 „ „ | |
| 1843 . . . | 3103 „ „ | |
| 1844 . . . | 3819 „ „ | In this year the mileage was materially increased. |

### CONCLUSION.

The principles set forth in this Paper have a *general* application to steam engines of every form, to the condensing as well as the non-condensing, to the fixed as well as to the locomotive.

A personal knowledge of many facts connected with the history and development of the locomotive engine upon the first field of its application to the transport of passengers and merchandise at high velocities,—the Liverpool and Manchester Railway,—has induced the writer to refer more frequently to the instance of the locomotive than to that of the fixed engine, for the purpose of illustrating his positions.

Nevertheless, the history of any one species of steam engine is in many respects the type of the history of the rest. There is observable in all, the same progress from imperfect and crude forms to those of a more advanced state of perfection; the same alternations of failure and success equally leading to the attainment of some fresh starting-point from whence a renewed extension of effort becomes possible.

The same agencies at work in one are at work in all. The source of heat is the same,—the means of transposing the heat into motive force are the same. Whatever differences in the results are found, may be referred to some peculiarity in the construction of the vessels or apparatus, or in the manipulation of them, by which more or less of the heat produced and motive force generated can be effectively applied to the wants of man.

Such differences of results admit of being accounted for and explained. Some will be found to arise from an essential difference in the principle of the engine, as in comparing the non-condensing with the condensing engine, or the condensing-inexpansive with the condensing-expansive engine. Some may arise from differences in the construction of subordinate parts, altogether irrespective of the want of conformity in principle, and which may therefore be considered in nowise incidental to the particular principle involved. Some again may depend on the amount of care and attention exercised by the parties in charge.

In the former case, nothing can be done by way of improvement without encountering as an obstacle the very principle of the engine itself.

In the latter cases, the remedy is found by applying in one instance what has been already applied advantageously in another.

No doubt, there remains yet great space for improvement in all classes of engines, both as respects principle and the methods of carrying out the principle; but at the same time there is the strongest ground for the belief, not only that the reduced performances of engines of the same class differ greatly from each other, but also that those of engines of different classes, when compared together, and due allowance made for difference of principle, are by no means in agreement.

Whilst this state of things continues, there is margin enough for improvement by attending to *methods* of working, without even touching the *principle;* and to this end it is only necessary that every owner of a steam engine, every one, in fact, who is interested in its economy, should make himself master of two sets of facts: 1st, the knowledge of the actual duty performed by his own engine; and 2ndly, the knowledge of what has been performed in similar engines, and of what therefore *may* be performed in his own. This comparison of duty would at once point to the advantages he may secure, and lead to obtaining them.

If, for instance, a certain class of boilers, known under the designation of Cornish boilers, but distinguished from other classes of modern boilers only or chiefly by the addition of such simple appliances as may serve to prevent undue dissipation of heat, has been found to evaporate considerably more water by a given weight of fuel than other descriptions of boiler, in which such appliances are not found, the inference is obvious, that what has been done in the one case may be equally done in the other. And if the Cornish engine, by the aid of its peculiar construction of boiler, and mode of firing, combined with the application of high-pressure steam and expansive working, has accomplished with 3 or 4 ℔s. of coal what the ordinary Boulton and Watt factory engine does with 10 ℔s., further progress may doubtless be made towards economy of fuel in the fixed engines of our manufacturing districts.

According to the returns quoted by Mr. Parkes, and heretofore cited, the best Boulton and Watt non-expansive condensing engines raise between 28,000 and 29,000 ℔s. 1 foot by 1 ℔. of steam.

According to Mr. Armstrong, who has much experience in the working of the engines in and around Manchester, those engines consume 10 ℔s. of coal per horse-power per hour, after deducting for various causes of waste and loss. This is a duty of 218,000 ℔s. raised 1 foot by 1 ℔. of coal; and assuming 1 ℔. of coal to evaporate 6 ℔s. of water, the engines raise 33,000 ℔s. 1 foot high by 1 ℔. of steam; a result rather better than that given by Mr. Parkes.

However paradoxical the statement may appear, the average performances of good locomotive engines which do *not condense* their steam are absolutely greater than those recorded of the Boulton and Watt *condensing* factory engines, notwithstanding the disadvantages under which the locomotive has been supposed to lie from its greatly inferior size of boiler,—from the great intensity of fire and rapidity of combustion,—from the necessity of procuring the draft by mechanical means,—and from the general exposure of its surface on every side to the cooling influence of the atmosphere.

In the year 1843, the average *gross* consumption of coke in luggage trains, (see Table,) with average loads of 20 waggons, or 100 tons, was 20 ℔s. per mile. Adding to this weight that of the engine and tender, say 20 tons, the gross load kept in motion by 20 ℔s. of coke per mile (or less, allowing for waste) was 120 tons.

If the sum of all resistances, whether arising from friction or from the action of the air on the surface of the train, but not including the atmospheric pressure against the pistons, or even the force expended on the blast, be taken at 8 lbs. per ton, the estimate must be considered a very low one.

Then the resistance of the entire train is

120 tons × 8 lbs. = 960 lbs.

Therefore the effect of the 20 lbs. of coke is 960 lbs. raised 1 mile or 5280 feet, equal to

5,068,800 lbs. raised 1 foot;

and the useful effect of 1 lb. *of coke* is

5,068,800 ÷ 20 lbs. = 253,440 lbs. raised 1 foot.

As 1 lb. of coke evaporates 7½ lbs. water,[13] the effect of 1 lb. *of water* is

253,440 lbs. ÷ 7½ = 33,792 lbs. raised 1 foot.

When it is considered that a pound of coke burnt in a locomotive engine whose boiler has hitherto been unjustly considered to belong to the most extravagant class, actually accomplishes as much as one pound of coal in the best reported Boulton and Watt non-expansive condensing engines, and more than twice as much as the same weight of coal in the best high-pressure stationary engines, it will appear reasonable to admit that there exists great room for improvement in most stationary engines.

Doubtless, also, there are great disparities in the work of individual engines of the same class, and of the same engine at different times, whether fixed or locomotive. These can only be reduced by the check of constant and close supervision, and an accurate appreciation of the causes which produce them.

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[13] From a temperature of say 50°.

# DIVISION A.—LOCOMOTIVE ENGINES.

SIXTH PAPER.

# DESCRIPTION

OF

# THE PATENT LOCOMOTIVE STEAM ENGINE

MADE BY

MESSRS. ROBERT STEPHENSON AND CO., OF NEWCASTLE-UPON-TYNE,

FOR CONVEYING THE EARTH EXCAVATED IN THE CONSTRUCTION OF A LINE OF RAILWAY.

WITH FOUR ELABORATE ENGRAVINGS,

AND NUMEROUS WOOD-CUTS TO EXPLAIN THE SEVERAL DETAILS.

THE following description of Messrs. STEPHENSONS' PATENT LOCOMOTIVE ENGINE was liberally contributed to the late improved edition of Tredgold's work on the Steam Engine by ROBERT STEPHENSON, ESQ., having been written under his direction by Mr. W. P. MARSHALL: in compliance with the expressed wishes of many of the Subscribers to the present edition, and at the recommendation of several professional friends, it is here repeated. The very elaborate illustrations present a model of an early patent, and the details are so perspicuously explained as to afford (for this or any other description of locomotive engine) the most ample information to the professional student and to the working engineer.

J. W.

JULY 1, 1849.

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ROBERT STEPHENSON AND CO., OF NEWCASTLE-UPON-TYNE,
FOR CONVEYING THE EARTH EXCAVATED IN THE CONSTRUCTION OF A LINE OF RAILWAY.

ALTHOUGH the original cost of these engines is very considerable, being about £1400 each, it is found to be advantageous to use them in executing the earthwork of railways when the earth has to be carried to any considerable distance, as they take the place of so many horses, and greatly expedite the work. They are also generally worth a great deal when done with for the particular purpose, as was the case with this engine, which was sold for upwards of two-thirds of its original cost. The expense of using them is nearly the same as that of doing the same work by horses, if the saving of time from the greater speed and heavier loads that can be carried are not taken into the account; but the advantage in these respects is so great that locomotive engines are generally used for the works of railways whenever the earthwork is of any considerable importance.

A locomotive engine differs considerably from other steam engines in many particulars, as the engine and boiler are combined together in one machine, and have to be carried along at a great velocity, together with the fuel and water required for supplying the boiler. Very considerable modifications in the construction are thus rendered necessary, in order to obtain sufficient lightness and compactness combined with the requisite power. The cylinders are very much smaller than is usual in other engines, the steam used being of very high pressure: the boiler is also made of small dimensions in proportion to the power, for the sake of portability, requiring therefore a construction affording the means of generating steam very rapidly, or having a great evaporating power, in order to supply the steam in sufficient quantity and of the required pressure. The whole engine has to be very strongly and firmly made and framed together, to enable it to resist the violent strains and shocks produced by the rapid motion of so heavy a mass, even upon the comparatively smooth surface of the rails, and also to meet the accidents to which it is liable, and which are generally very serious.

The construction of these engines has undergone very great and extensive improvement during the last few years, and they have not long arrived at their present state of perfection: those made before the last ten years were greatly inferior, having not more than a fourteenth of the power of the present ones.

The engine here described, and shown in the engravings, contains the latest improvements, and is similar in construction to most of those used on railways in England and on the Continent.

## DESCRIPTION OF THE ENGINE.

Plate I. is a side elevation of the engine and tender. The engraving is highly shaded to show more fully their general appearance.

Plate II. a longitudinal section through the centre of the engine and tender, showing their internal construction; the section below the boiler being taken through the right-hand cylinder and crank.

Plate III. Fig. 1 is a plan of the engine and tender: the plan of the engine is taken just below the boiler, in order to show the machinery beneath it, and at the left cylinder the plan is taken a little lower down, showing a section of the steam chest and more of the machinery: figs. 2, 3, and 4 are detached views of the working gear for the slide-valves; figs. 2 and 3 being side elevations, showing the working gear in different positions, to explain their action; and fig. 4 a back elevation, showing it in the same position as figs. 1 and .3. The plan of the tender is taken at the top.

Plate IV. contains an elevation of each end of the engine, and a cross section through each of the end portions.

The Plates are all drawn to a scale of three-quarters of an inch to a foot, or one-sixteenth of the real size, and the same letters of reference are used to denote the same parts in each of the figures.

The different parts of the engine are shown in detail on a larger scale in the wood-cuts accompanying the descriptions, according to the size or importance of the parts.

The construction and object of the different parts of the engine will be explained in succession, together with the wear to which they are subject, the improvements that have been made in them, and the principal variations in construction from other engines.

The general order of description will be,—I. The Boiler, and the Manner of generating the Steam, with the means of supplying the boiler, of cleaning it out, and of insuring its safety; also of ascertaining the pressure of the steam, and the quantity of water.

II. The Cylinders, and the Manner of using the Steam, with the mode of supplying the cylinders with steam, and working the pistons and slide-valves; and of moving the wheels and propelling the engine.

III. The Wheels, Framing, &c., of the Engine, with the springs, axle-boxes, and guides, &c., connected with the frame.

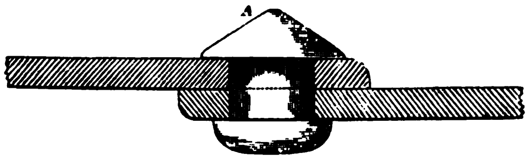
IV. The Tender, for carrying coke and water to supply the boiler.

## THE BOILER, AND THE MANNER OF GENERATING THE STEAM.

The boiler consists of several distiuct parts: the cylindrical portion A, called peculiarly the boiler; the external fire-box B, communicating with it; the internal fire-box C, containing the fire-grate D; and the tubes E, communicating between the internal fire-box and the smoke-box F, upon which is fixed the chimney G.

The Boiler AA (Plates I. and II.) is a cylinder 7 feet 6 inches long, and 3 feet 6 inches in diameter outside; it is made of wrought iron plates five-sixteenths of an inch thick, lapping over each other, and joined together by iron rivets seven-eighths of an inch in diameter and 1¾ inches apart, as shown at A in fig. 5, which is a section of a joint, half size. The rivets are inserted red-hot, and contract in cooling, drawing the plates forcibly together, and making a very close joint.

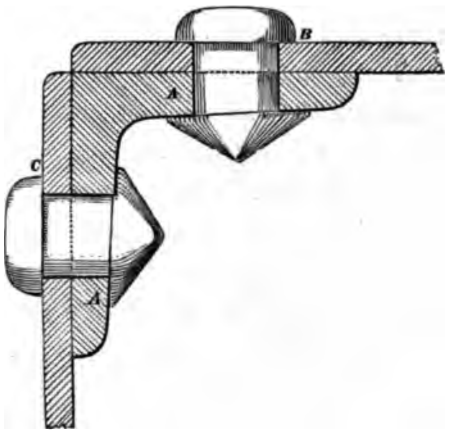
Fig. 5.



The boiler is covered with wood *a a* (Plate II.), one inch thick, put on in longitudinal staves, and bound round by the iron hoops *b b* (Plates I. and II.), which are screwed together at the bottom: this casing of wood is for the purpose of retaining the heat, and preventing it from being carried off by the air when moving rapidly through it, wood being an imperfect conductor of heat.

The External Fire-Box BB is a box nearly square, 4 feet wide outside, and 3 feet 7½ inches long in the direction of the boiler, made of wrought iron plates five-sixteenths of an inch thick, like those of the boiler; the bottom is 2 feet 1 inch below the boiler, and the upper part is a semi-cylinder, concentric with the boiler, as shown in the cross section, fig. 2, Plate IV. The fire-box is open at the bottom, and has a circular opening cut in the front side, of the same size as the boiler, and corresponding to it; the boiler being fastened to it by means of angle iron *c c* (Plate II.), as shown in the section, half size, in fig. 6: the angle iron A is bent round the boiler at the place of its junction with the fire-box, and riveted to the plates B and C of the boiler and fire-box. The plates composing the front and back of the fire-box are bent inwards at right angles all round, as at *d d* (Plate II.), forming flanches upon which the plates of the sides and top are riveted.

Fig. 6.



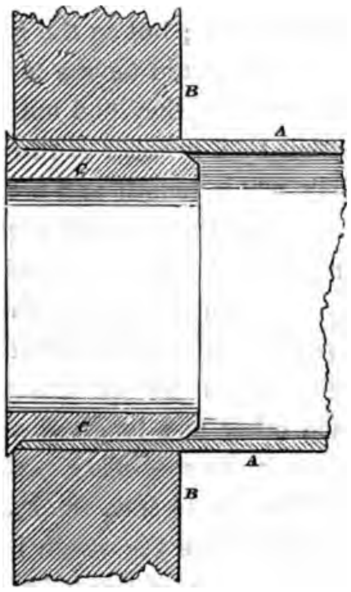
**The Internal Fire-Box** C C is of similar shape to the external, but flat at the top, and closed at all sides except the bottom; a clear space of 3½ inches is left all round between it and the external fire-box, and on the side next to the boiler the space is 4 inches. The internal fire-box is made of copper plates seven-sixteenths of an inch thick, except the side next the boiler, which is seven-eighths of an inch thick; but all of the plate except the circular portion opposite to the boiler is beaten down until it is only seven-sixteenths of an inch thick, the same as the rest. The roof and sides of the box are formed of one plate, as shown in the section, fig. 2, Plate IV., and another plate forms the back, corresponding to that in the front next the boiler: the front and back plates are turned inwards at the edges, like those of the external fire-box, and the other plate fixed to them by three-quarter-inch copper rivets. The internal fire-box is fastened at the bottom to the external by setting the plates out until they touch the outer plates, and riveting them together with copper rivets, as shown at *ff* (Plates II. and IV.). The plates are sometimes set out only so as to approach the outer plates within 1½ inch, and a copper ring inserted between them, the rivets being put through the ring, and the joint thoroughly closed by hammering it up underneath; but it is generally found that the joint keeps water-tight best when made by setting the plates together and riveting them: a double row of rivets is generally used. An oval hole, 14 inches wide and 12 inches high, is cut in the back plate of both fire-boxes for the fire-door *g g* (Plate II., and fig. 1, Plate IV.); the plate of the internal fire-box is set out all round it to meet the outer plate, and the two are fixed together by a row of copper rivets: a copper ring is sometimes inserted between the plates here, as well as in the joint at the bottom of the fire-box. The fire-door consists of two wrought iron plates connected together by rivets, leaving a space of half an inch between them: this protects the outer plate from the fire, and prevents it from getting too hot.

The fire-grate D D is fixed 3 feet 2 inches below the roof of the fire-box, and 9 inches above the bottom, and is composed of separate loose bars of wrought iron, 2½ inches deep in the middle, and 1 inch thick at the upper side, tapering downwards to allow more free ingress for the air: the fire-bars are bent down at the ends and drop into holes in a square ring of iron, *h h*, which runs round the fire-box at a little distance from the side, and is supported by a piece of angle iron, *i i*, bolted to the front and back plates of the fire-box. The fire-bars are made separate and moveable, in order that they may be easily replaced when worn out, which happens very frequently from the great heat to which they are exposed; and also for the facility with which the fire can be extinguished in case danger should be apprehended from any accident; for by lifting them out of the holes with a bent rod, kept for the purpose, they can be dropped, together with the whole of the fire, upon the road: this is indeed the manner in which the fire is extinguished when the engine has done working. An ash-pan is fixed under the fire-box in some engines, made of sheet iron, of the same shape as the external fire-box, and open only in front; it serves to catch the cinders and prevent their falling on the road, but is rather inconvenient when the fire has to be let out.

The boiler, being cylindrical, has an equal strain in all directions from the pressure of the steam; but as the fire-boxes are flat on all sides except the top of the external one, they would have a tendency to be separated from each other by the pressure of the steam, if they had not some support. For this purpose they are connected together by a number of three-quarter-inch copper bolts, *k k*, which are screwed along their whole length and are passed through holes in both plates, tapped to receive them, and then riveted over at the ends for additional security: these copper bolts are screwed in about 4 inches apart all over the sides and back of the internal fire-box and that portion of the front that is below the boiler. As the roof of the internal fire-box only requires support, that of the external one being cylindrical, it is strengthened by six wrought iron ribs, *l l* (Plates II. and IV.), placed parallel to each other and longitudinally upon the roof, and fastened to it by bolts screwed through the roof-plate, and having, in addition, a nut screwed on at the under side: the ribs are 1¼ inch thick, and increased at the bolt-holes, and 2½ inches deep at the middle, where the strain is greatest. The ribs, *l l*, are cut away on the under side between each of the bolts, so as to touch the roof-plate only where the bolts pass through them, in order that there may be as little mass of metal as possible exposed to the immediate action of the fire; for when a considerable thickness of metal is interposed between the water in the boiler and the fire, the heat cannot be absorbed by the water with such rapidity as it is supplied, and the metal becomes in consequence greatly heated, and is rapidly destroyed. The durability of the internal fire-box depends very much on the care of the engine-man: with proper use it will last several years, but if the water is allowed to get too low in the boiler, so as to have but little depth over the roof, the plate will be liable to get frequently uncovered, from the motion of the engine, and be rapidly destroyed. To prevent this accident, a small plug of lead, *m* (Plates II. and IV.), is put through a hole in the centre of the roof of the fire-box, and riveted over on both sides: when the water gets so low as to uncover this plug, it is melted by the heat, and the steam, rushing into the fire-box, extinguishes the fire. The internal fire-box is made sometimes of wrought iron, and is generally found to last nearly as long as a copper one; the iron fire-box costs considerably less, but requires more care in using, and is very liable to crack and become leaky at the joints.

TUBES.—The communication between the fire-box and the chimney is made by a number of tubes, E E (Plates II. and IV.), which are fixed water-tight at one end into the front plate of the fire-box *e*, and at the other into the plate *n* (Plate II.), which closes the front end of the boiler; the tube plate, *e*, of the fire-box being made thicker where the tubes are inserted, to allow for its being weakened by the holes cut in it. There are 124 of these tubes; they are $1\frac{5}{8}$ inch in diameter outside, and a space of three-quarters of an inch is left between them. They are made of the best rolled brass, one-thirteenth of an inch thick, (called No. 13 wire-gauge;) the edges of the brass are properly chamfered and lapped over each other and soldered together, the solder being applied inside: the tubes are then drawn through a circular steel die, to make them truly cylindrical. The holes to receive them in the tube plates *e* and *n* (Plate II.) are bored quite cylindrical, so as to fit the tubes exactly, which are just long enough to come to the outside of both plates: the ends of the tubes are then fixed by driving in a steel hoop or ferrule, made slightly conical, as shown in fig. 7; which is a section, full size, of the tube A A, the plate of the fire-box B B in which it is inserted, and the ferrule C C: the ferrule is a little larger than the tube, so that, when driven in, it compresses the tube very forcibly against the sides of the hole, and makes the joint completely water-tight. The ferrules are sometimes made of wrought iron, but they generally do not last out the tube in that case, and require replacing by new ones before the tubes are worn out: the steel ferrules are better, as they last nearly twice as long. When a tube or a ferrule requires taking out, the ferrule has to be cut quite through with a chisel, and then turned inwards, so as to detach it from the tube, which can then be driven out.

Fig. 7.



By causing all the flame and heated air to pass through a great number of small tubes surrounded by the water, a very great and rapid means of heating the water is obtained, as a very large heated surface is thus exposed to the water. The first locomotive engines had merely a large flue passing from the fire-place to the chimney; it was bent round at the end and returned again to the back, the chimney being placed at the same end as the fire-place; the fire was contained in the commencement of the flue, which was made larger for the purpose. This is the general principle of the construction of the boilers for stationary engines where the size and weight of the boiler are not of so much importance, and the flues can be made large enough to get a sufficient area of heated surface in contact with the water. But as in a locomotive engine all the machinery has to be moved at a great velocity, the size and weight of the boiler are obliged to be diminished very much, and some other means has to be adopted to obtain the requisite heating surface.

The 'Rocket' engine, made by Mr. R. Stephenson, which was the engine that gained the prize for the best locomotive, at the opening of the Liverpool and Manchester Railway in 1829, was the first engine made with tubes in this country.[1]

The former locomotives with only a flue through the boiler had never been able to travel faster than about eight miles an hour, as they had not sufficient heating surface in the boiler to generate the steam for supplying the cylinders more rapidly; the speed attainable by a locomotive being limited only by the quantity of steam that can be generated in a given time. The introduction of tubes into the boiler is one of the greatest improvements that has been made in the construction of locomotives, and was the cause of the superiority of the 'Rocket' engine to those that competed with it, and to all the former engines. The velocity it attained at the competition trial was 29 miles an hour, and the average 14½ miles an hour.

The tubes of the 'Rocket' engine were 3 inches in diameter, and only twenty-four in number: in the engines made subsequently, the size was reduced, and the number of them doubled and trebled, by which means the heating surface was very much increased, and with it the power of the engine. The smaller the tubes are, the greater is the heating surface obtained, as small circles have a much larger circumference in proportion to their area than large ones; but when the tubes are diminished in size, the total area of passage through them from the fire-box to the chimney is also diminished; and consequently if the diameter of the tubes were much diminished, the draught of the fire would be checked from the passage to the chimney being too small. The heating power of the boiler would thus be injured, although the amount of heating surface exposed to the water was increased, and the abstraction of the heat from the hot air rendered more perfect. The exact size of tubes which produce the best total effect is to be discovered only by experience, and has not yet (1838) been completely decided.

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[1] It appears that the merit of the first invention of a boiler with tubes is due to a French engineer, M. Seguin, who had a patent for it in 1828; although the application of the principle in the 'Rocket' engine was undoubtedly an independent invention.

Small tubes have another disadvantage in being liable to choke up very much with the particles of coke which are carried through them in great quantities by the force of the draught, and in their retaining the cinders which are continually blown into them, but which pass clear through larger tubes. The small tubes are often contracted one-third in diameter by the deposit of coke on their inner surface during the day's work, and they have to be cleared out every night by passing a rod through them: the larger tubes never require clearing out.

The tubes were at first made of copper, and some have been of wrought iron, but the copper tubes were found to wear very fast, generally lasting only three or four months, and were a great source of expense from the necessity of frequently renewing them. Brass tubes were first tried in the locomotives on the Liverpool and Manchester Railway in 1833, at the suggestion of Mr. Dixon, the resident engineer, and were found to be very much superior; they are now universally used for locomotives. Brass tubes, of the dimensions mentioned above, last about two years, being six or eight times as long as copper tubes of the same dimensions. This increase of durability appears partly caused by their greater hardness, as it has been observed that the soldered joint, which is made with harder brass, wears less than the other parts; but the whole cause has not yet been satisfactorily ascertained. The tubes are much worn by the friction of the cinders that are blown through them by the force of the draught; but it is very probable that their wear is principally caused by chemical or thermo-electric action. The tubes in the middle and about the fourth row from the bottom are worn out the first, and it is only the ends next the fire-box that are destroyed.

When the tubes become very thin they are crushed inwards by the force of the steam, and the water is blown out at the ends of the tube into the fire: when the tubes are getting old, this frequently takes place whilst an engine is running, and it is stopped by the accident. A plug of hard wood is driven into each end of the burst tube, which is preserved from being burnt by the contact of the water inside the tube, and the engine runs on again. When several of the tubes have burst and been plugged up, they are taken out and replaced by new ones; and if the engine is required to be in constant use, a complete set of new tubes is soon required to avoid the liability of delays from the bursting of the tubes: they weigh about 16 ℔s. when new, and lose about 6½ ℔s. in the time they are in use. The cost of the brass and of the copper tubes is about £1 each, and this makes the expense of repairing an engine very considerable when a complete set of new tubes is required. The tubes being fixed firmly into both ends of the boiler, it serves to support and strengthen them; but for an additional support to the upper part, six wrought iron rods, *o*, *o* (Plates II. and IV.), are placed above the internal fire-box, by the side of each other, and longitudinally in the boiler; and the ends are attached by a pin to a piece of wrought iron, called T iron, riveted on to the end plate of the boiler and to the back plate of the fire-box.

THE SMOKE-BOX, F F, is 4 feet wide, like the fire-box, and 2 feet long, and is closed on all sides; the back of it is formed by the wrought iron plate *n*, half an inch thick, closing the end of the boiler to which it is attached by means of a piece of angle iron riveted to both, like the similar joint at the fire-box. The rest of the smoke-box is made of quarter-inch iron plate, the front and back plates being bent in round the edge, and the other plates riveted to them, as in the fire-box, except the front plate, which is fixed by screw-bolts and nuts, because it is required occasionally to take it off.

Upon the smoke-box is fixed the chimney G (Plates I. II. and IV.); it is 15 inches in diameter, and is made of one-eighth-inch iron plates, riveted together and bound round by hoops, as shown in the section; the top is made funnel-shaped to give more free egress to the hot air, and the bottom has a piece of plate riveted to it, forming a flanch all round, by means of which the chimney is bolted down upon the smoke-box.

In the lower part of the smoke-box are fixed the two cylinders H H, where the steam is used and motion produced: these will be described afterwards. The steam, when it has been used in the cylinder and has performed its work, is no longer wanted, and is let out into the air by the pipe *p*, (Plates II. and IV.)

The tubes open into the upper part of the smoke-box, and the hot air passes from them up the chimney: no smoke is produced, except at first lighting the fire, as the fuel used is coke, which does not cause any smoke in burning, but only a light dust. The height of the chimney is obliged to be small, as it can never exceed 14 feet height from the rails; so that the draught produced by it is not at all sufficient to urge the fire to the intense degree of ignition that is necessary to produce steam at the pressure and in the quantity that is required, and some other more powerful means has therefore to be adopted to produce the draught. This is done by making the waste steam issue through the pipe *p p* (Plates II. III. and IV.), called the blast-pipe, which is directed up into the centre of the chimney, and is gradually contracted throughout its length to make the steam rush out with more force: this pipe is made of copper one-eighth of an inch thick, and is 3¾ inches in diameter inside at the bottom, where it joins on to the cylinders, and tapers to 2½ inches at the top.

The waste steam rushes out of the pipe with great force up the chimney, carrying the air with it, and causing a very powerful draught through the tubes and the fire: a whole cylinder full of steam is let out at each stroke, and the two cylinders deliver their waste steam alternately, so that when the engine is running fast an almost constant current of steam in the chimney is produced, and the interval between the blasts can scarcely be perceived. By this method the fire is not blown, as is usual, by forcing air into it, but by extracting the air from the flues and drawing air through the fire. In the first locomotives no means were used for increasing the draught of the chimney, and their power of generating steam was consequently very limited: the introduction of the steam blast for urging the fire, and of the tubes for conveying the heated air through the water, are the principal causes of the great power of the present locomotives.

There is, however, a considerable loss of power attending the use of the blast-pipe, from the obstruction it causes to the egress of the waste steam; for the waste steam opposes the action of the steam in the cylinders, and should be allowed to escape freely, that its pressure may be as small as possible. This causes the greater economy of working in the large stationary and marine engines, where the waste steam is condensed and its opposing pressure is reduced almost to nothing; but in a locomotive engine, on the contrary, its average resistance is not less than 6 ℔s. on the square inch; and when running very fast, and the issue of waste steam is almost continuous, the whole loss of power amounts to nearly half that of the engine. But the draught must be obtained by an expenditure of some of the power of the engine, whatever means may be employed to produce it; and the plan of producing it by the blast of waste steam is the best, as no power is wasted upon working any machinery for the purpose, and it has the advantage of great simplicity in its application. In some locomotive engines, made by Messrs. Braithwaite and Ericcson, a revolving fan-wheel, worked by the engine, has been used to perform the same operation of drawing the air from the flues; and in the 'Novelty,' by the same makers,—one of the engines that competed for the prize on the Liverpool and Manchester Railway,—air was forced into the fire-box, but that plan was afterwards abandoned from its being found not so advantageous.

The force of the draught produced by the steam blast is so great that cinders are drawn through the tubes and even thrown red-hot out of the top of the chimney; sparks are also emitted occasionally, and have sometimes caused accidents. To prevent the cinders and sparks from getting out of the chimney, a wire sieve is often fixed on the top of the chimney, but this has a disadvantage in impeding the draught and the exit of the waste steam very considerably; though it is made convex and larger than the chimney, so as to have a larger surface, and to impede the passage as little as possible. The sieve is, however, but an imperfect remedy, for the cinders are thrown against the sieve with so much force that the meshes are soon destroyed. A sieve has been tried, placed at the bottom of the chimney, so that the blast-pipe ran through it, and in this position it afforded much less obstruction to the draught than when placed at the top of the chimney; for the blast of steam which produces the draught being entirely above it, would not be impeded, and the loss of power from impeding the exit of the waste steam would also be avoided. But the plan was afterwards abandoned, as the sieve was found to be destroyed so quickly as to require constant repair, from being exposed immediately to the air, and to all the cinders, that are drawn through the holes, striking against the front plate of the smoke-box, and rebounding upwards towards the chimney.

DAMPER.—II (Plates I. II. and IV.) is a damper placed in the chimney just below the top of the blast-pipe, consisting of a thin iron plate fitting the chimney closely, with a hole cut in its centre, just large enough to allow the blast-pipe to pass through. A flat bar is bolted on to it, to serve as a spindle, and fixed a little out of the centre, in order to clear the blast-pipe when the damper is elevated, as shown in Plate II. This spindle is made round at each end, and turns in bosses riveted to the outside of the chimney; one end passes quite through, and has a short lever, *q*, fixed on to it: the diameter of this end of the spindle is of the same size as the width of the flat part, to allow of the spindle being put into its place through the hole in the boss in which it turns, before it is attached to the damper in the chimney. A long rod, *r r* (Plates I. and II.), is attached to the lever, *q*, on the spindle, and reaches to the top of the fire-box, terminating in a handle, and resting in an iron fork, *s*, fixed in the top of the fire-box, in which either of two notches made in the rod can catch; so as to hold the damper either vertical, as in Plate II., or in a horizontal position, closing up the chimney, as shown by the dotted lines across the chimney in Plate II.

The damper is used to check the draught when a less intense action of the fire is required, such as when the engine is standing still or running down hill, and very little power is wanted; it causes very little obstruction to the exit of the waste steam, as the blast-pipe passes through it. It is a curious circumstance, that whilst the damper is raised, the waste steam passes out of the chimney in an invisible state, unless the atmosphere is nearly saturated with moisture, from the increased capacity of the hot air for moisture enabling it to absorb the steam in the chimney. A slight change in the dryness of the atmosphere, or the temperature of the engine fire, causes the steam to be visible; and hence it is always visible in winter, and in summer is invisible only when the hygrometer is high; its appearance is, indeed, a tolerably correct indication of the hygrometric state of the atmosphere. When the damper is lowered, the steam instantly becomes visible from the want of hot air to absorb it, and it then issues from the chimney in dense white volumes.

SMOKE-BOX DOORS.—A large door, *t t* (Plates II. and IV.), is made in the front plate of the smoke-box, for the purpose of affording access to the cylinders and the tubes: there is a ledge fixed inside round the opening, against which the door is closely pressed by four finger-nuts put upon screws fixed in the smoke-box plate, and passing through projecting lugs upon the door. There is also a small door, *u*, near the bottom of the smoke-box, for the purpose of clearing out the cinders and ashes that collect in it: both doors have to fit closely, that no air may enter at them to impair the draught.

FEED-PUMPS.—The boiler is supplied with water by the two feed-pumps, K K, which are worked by the engine: their construction will be explained afterwards. One of them is sufficient to supply the necessary quantity of water for the boiler, and the other is thrown out of action; but two are furnished in the engine, in order that if one should fail from any accident, the other may take its place without any delay being caused. On forcing the water into the boiler, it checks the generation of steam by its coldness, and the effect of the engine is also diminished in consequence of the power required to work the pump: for this reason the action of the feed-pump is generally suspended when the engine is ascending an inclination, and requires its greatest power, and the supply of water is made up by working both pumps on a succeeding level or descent: this is an additional advantage in having duplicate pumps. A small cock, called the pet-cock, is fixed in the pipe leading to the boiler from each pump, and a long handle, *v*, is fixed to it, extending to within reach of the engine-man standing behind the engine: these cocks are opened occasionally to ascertain whether the pumps are working properly, when a stream of water should be forced out at each stroke.[2]

GAUGES. —L L (Plates II. and IV.) is a glass gauge for showing the height of the water in the boiler; it is shown detached in fig. 8, which is a section through the centre of it, to a scale of 2¼ inches to a foot, or three times the size of the engraving. The gauge consists of a strong glass tube, A, fig. 8, about three-quarters of an inch diameter outside, fitted into a brass socket, B B, at top and bottom, the joints being made steam-tight by hemp packing, put round the glass, and compressed against it by the glands, C C, which are screwed in round the glass. From each of the socket-pieces, B, a tube, D, proceeds, with a cock in it, and a screw on the end for fixing it into the fire-box; and the piece E, containing another cock, is screwed into the lower piece, and the plug F into the upper piece, affording the means of putting the glass tube down into its place. When the two cocks D D are opened, the water of the boiler rises in the glass tube to the same height that it is in the boiler, the upper part of the glass being filled with steam; the height of the water in it showing always the level of the water in the boiler: the cocks are for the purpose of stopping the communication, when required, from the gauge being out of order, or otherwise. The cock in the piece D is for the purpose of clearing out the gauge, by allowing a stream of water to run through it; and it is often necessary to open it, when examining the gauge, in order to get rid of the bubbles of steam formed by the rapid ebullition of the water, which sometimes render it difficult to ascertain the precise height of the water. The difficulty is also increased by the motion of the engine producing oscillation in the water; but the disturbing effect is much diminished by choking the tube, or making the communication with the boiler through the tube D very small, so as to impede the motion of the water in the tubes. A small plug, G, is screwed in opposite each tube D, to afford the means of clearing out the tubes D, by passing a wire through them when the plugs G are taken out.

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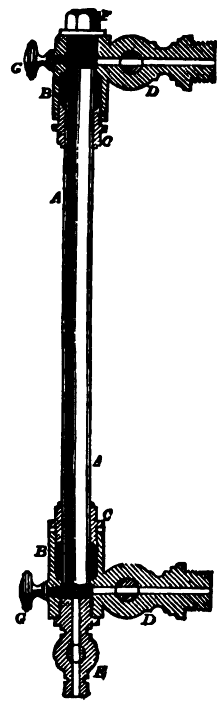
[2] The *pet-cock* was invented by Mr. George Stephenson, to obviate what was for some time an incurable defect in the feed-pumps of locomotive engines: the pumps could not be made to keep in action, as they were fixed close to the boiler, and hot water entered from the leaking of the valves, causing them to be filled with steam instead of water at each stroke; thus preventing them from forcing any water into the boiler, which could, therefore, be used only for a short time, whilst the water in it would last, the boiler having then to be emptied of steam and re-filled. The cause of this stoppage of the action was at length discovered, and the *pet-cock* applied, by opening which the steam in the pump was let out, and the action renewed: the name was given to it playfully, from its petting or coaxing, as it were, the pump to do its duty. It is not now required for this purpose, as the pump is separated from the boiler by a long tube with a valve at each end, and the hot water cannot get into it.

Fig. 8.

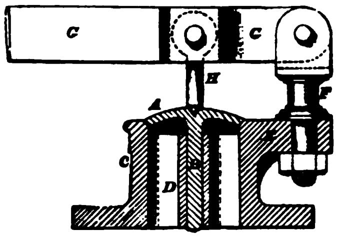


To afford an additional means of ascertaining the height of the water in the boiler, two gauge-cocks, M M, are fixed in the side of the fire-box, one being four inches above the other, and the lower one, one inch above the top of the internal fire-box. The boiler is generally filled at starting, until the water runs out at the upper cock; and during working the water level is kept between the two cocks, and often up to the upper one. The cocks are opened occasionally to try the level; and if steam should ever be found to blow out at the lower cock, showing that there is not more than one inch of water over the roof of the internal fire-box, instant attention has to be paid to the feed-pumps, and the fire damped, if necessary, to prevent the roof of the fire-box being uncovered and getting burnt. The glass tube is, however, the more certain guide, being less affected by the oscillations of the water than the gauge-cocks.

The Lead Plug, *m* (Plates II. and IV.), described before, is an additional security against any accident arising from the water being suffered to get too low in the boiler.

Safety-Valves. — The pressure of steam in the boiler is regulated by the safety-valve, N (Plates I. II. and IV.), the construction of which is shown in figs. 9 and 10, drawn to a scale of 2½ inches to a foot, or three times the size of the engraving. Fig. 9 is a longitudinal section through the valve; and fig. 10, a plan of the valve-seat with the valve removed. The valve A is made of brass: it is conical round the edge, or mitred at an angle of 45°, and has a spindle or stalk, B, cast on it in the middle. The seat C of the valve is also of brass, and is cast with a flange at the bottom, to bolt it on to the boiler; and the valve is ground into the upper part, so as to fit it steam-tight. The opening in the valve-seat, C, is 2½ inches diameter, and across it is cast a thin piece, D, extending to the bottom, and having a longitudinal hole through it, in which the spindle B of the valve works: this is to hold the valve steady when it is raised, and to guide it into its seat again. A projecting lug, E, is cast on the valve-seat, in which is fixed the standard, F; this is forked at the top, and receives the end of the lever, G, which turns in it upon a centre pin; a rod, H, is jointed to the lever by another pin, at 3 inches from the former one, and bears directly upon the valve.

Fig. 9.



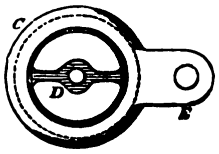


Fig. 10.

At the other end of the lever, and at a length of 3 feet from the fulcrum, is attached by a finger-nut the rod of a common spring balance, *w* (Plates I. and IV.), the bottom of which is fixed on to the fire-box: this spring balance is screwed up by the finger-nut on the valve lever, until the required pressure on the valve is produced, which is generally 50 lbs. on the square inch above the atmosphere; and the valve, on rising to let out the surplus steam, has to raise the spring balance, which acts upon it with twelve times the leverage.

In stationary engines, the safety-valve is kept down by a weight hanging on the lever, and shifted to different positions, to alter the pressure on the valve; but in a locomotive engine a weight could not be used, because the motion of the engine would cause it to jolt up and down, and the valve would be continually letting off steam. There is one disadvantage attending the use of the spring balance that the other plan is free from; namely, that any opening of the valve by raising the lever, compresses the spring in the balance more, and increases the pressure upon the valve, so that the free egress of the surplus steam is checked, and the pressure of the steam is allowed to become greater than that indicated by the balance when the valve is shut: the longer the lever is, the greater is this difference of pressure, and it is sometimes as much as 10 lbs. per square inch.

In observing the pressure on the safety-valve, allowance must also be made for the effect of the mitre, or conical part of the valve; for when it is raised, the steam acts on the conical part as well as on the bottom of the valve, and has therefore a greater power in lifting the valve; and this diminution of the pressure on the valve varies with the extent of the mitre and with the degree that the valve is opened.

These different circumstances render the safety-valve but an imperfect means of ascertaining the pressure of the steam in the boiler. In stationary engines, which are generally worked at a much lower pressure, a mercurial gauge is often used to indicate the pressure of the steam; but this instrument cannot be used in a locomotive, as a tube of great size, and not less than 12 feet high, would be required: it has, however, been used as a means of testing the accuracy of the indications of the safety-valve by a temporary connection with the engine.

O (Plates I. and II.) is the lock-up safety-valve, enclosed in a case, to prevent access to it so as to increase the pressure to a dangerous degree. The valve is exactly similar in construction to the other safety-valve, but instead of being held down by a lever and spring balance, several small elliptical springs, *x x* (Plate II.), about 6 inches long, are placed one above another and over the valve, and pressed down by a screw at the top in the frame *y y*, fixed into the valve-seat. By turning this screw, the pressure on the valve can be adjusted to any required degree; and when the case is fixed on, the valve is effectually protected from having the pressure altered. The lock-up valve is loaded rather more heavily than the ordinary working pressure, 50 lbs.; so that it does not blow except when the pressure has exceeded that limit, as in performing work requiring more power than usual.

A large spiral spring is used in some engines to press upon the valve, being fixed in a similar manner to the elliptical springs; it is rather more compact, but is not quite so free in its action, as the pressure increases more rapidly on the using of the valve.

MAN-HOLE.—P (Plates I. and II.) is a circular opening into the boiler, called the man-hole; it is 16 inches in diameter, and surrounded by a ring, *z* (Plate II.), bolted on to the boiler, having a flanch at the top for fixing on the cover. This opening is large enough for a man to enter, and affords access to the interior of the boiler for making repairs in it, or for cleaning it out.

MUD-HOLES.—These are two small openings, Q Q, in both sides of the fire-box at the bottom, closed by plates bolted upon the outside, and are for the purpose of cleaning out the fire-box and removing the sediment that is deposited from the water. Two mud-holes, at opposite corners of the fire-box, are usually opened twice a week, and the deposit washed out by directing a stream of water into them; each pair of opposite holes being opened alternately. The boiler does not often require cleaning, but it is occasionally washed out by putting the water hose in at the man-hole, and washing all the sediment into the fire-box: this is found to be quite sufficient to keep it clean.

BLOW-OFF COCKS.—R R are two cocks, one inch in diameter, fixed one in each side of the fire-box, close to the bottom, for the purpose of emptying the boiler; this is called *blowing off*, as it is done just after the engine has left work, and the water is blown out with great force by the pressure of the steam. This blowing off serves to cleanse the boiler, and the whole water has to be thus emptied out two or three times a week when the engine is in full work, as it gets foul after remaining in the boiler for some time.

FIRE AND HEATING POWER.—The fuel used is coke, and is that most generally used in locomotives: coal was employed in the first ones, and is now made use of on railways in the collieries and where passengers are not carried; but on the large public railways it is inadmissible on account of the smoke that is produced. Coke has an advantage over coal in being very light in substance and not caking together, but allowing the draught of air to pass freely through the fire; it is also capable of attaining a very intense degree of ignition; but its lightness renders it more liable to be drawn through the tubes by the draught, and the fine dust or ashes, produced by its combustion, is very annoying to outside passengers. The coke used is of the best quality; and the operation of coking the coal is performed only with a view to the abstraction of the volatile parts, as the hydrogen, and the losing as little as possible of the carbon: gas coke, or the remains of the coal used in gas works, is very inferior, being overburnt, and having lost a good deal of its carbon to form the gas, carburetted hydrogen: it also contains a good deal of sulphur, which is very injurious to the metal of the boilers: this causes also the principal objection to the use of coal. The coke used in the locomotives on the London and Birmingham Railway is made upon the works, and is very nearly pure carbon. Welsh stone coal or anthracite has been also tried; it produces no smoke or flame, being almost pure carbon, like coke; but it appears to be not suited to locomotives, from its density and flying into small pieces, so as to form a close mass on the fire-grate, and not allow a sufficiently free passage for the air through the fire.

The fuel is carried in the tender behind the engine and immediately contiguous to the fire-door, so that it can be readily shovelled into the fire when required: it is supplied on an average in quantities of about half a cwt. at intervals of from five to ten minutes. The heating the water in the boiler and getting up the steam takes about an hour and three-quarters on an average, and requires the consumption of about one and a half or two cwt. of coke: in some places the boiler and tender are supplied with hot water by means of a stationary boiler, in order to expedite the getting up of the steam, and also as a means of economy.

The area of the fire-grate is 9½ square feet; it is 18 inches below the bottom of the lowest tubes, and the space for the fire, when quite filled up to the tubes, is 14 cubic feet, and holds about 2½ cwt. of coke; but the fire-box is not always filled so full as this, and usually contains about one and a half or two cwt.

The surface of water exposed to the heat directly radiated from the fire is the whole surface of the internal fire-box, deducting the fire-door and the tubes, and is equal to 50 square feet; and that exposed to the current of hot air, or conducted heat, is the interior surface of the tubes, and is equal to 432 square feet. The surface exposed to radiated heat is considerably more efficacious in generating steam than that exposed to conducted heat only, as the supply of heat is more copious, and the proportion was found to be about three times in an experiment tried by Mr. Stephenson, which is the only one that has been made upon the subject: the experiment was made with an old engine, and the proportion may be somewhat different in the modern engines.

The area of passage for the heated air from the fire-box to the chimney is the sectional area of all the tubes inside the ferrules; the ferrules are three-eighths of an inch less than the outside of the tubes, and are therefore an inch and a quarter in diameter inside; and the sectional area of them all (124 in number) is 1·06 square ft. The area of the passage through the chimney is rather more, or 1·23 ft.

In the 'Rocket' engine the area of passage through the tubes was ·90 square ft., or nearly the same as in this engine, though the fire-grate was but half the size; but the heating surface of the tubes was only one-third, from the large size and small number of the tubes: the heating surface of the fire-box was only three-quarters of that of the present engine.

In the old engines before the 'Rocket,' the area of passage through the flue was two and a half times the size, but the heating surface was only one-thirteenth of that in the present engine; the fire-box had also only one-fifth of the heating surface; the fire-grate was three-quarters of the size.

## THE CYLINDERS, AND THE MANNER OF USING THE STEAM.

Steam-Pipe.—S S (Plates II. and IV.) is the steam-pipe for conveying the steam from the boiler to the cylinder, where it is to be used; it is made of copper three-sixteenths of an inch thick, and the part within the boiler is 5 inches diameter inside; it passes through the tube plate of the smoke-box and is bolted to it by a flanch. The pipe then divides into two smaller ones, 3½ inches in diameter, which pass down on each side of the smoke-box to the cylinders, as shown in Plate IV. fig. 4; they are turned on one side in order to keep them clear of the tubes, so as to allow access to all the tubes, that they may be taken out, when necessary, through the smoke-box door. It is also necessary to protect the steam-pipes from the immediate action of the hot air issuing from the tubes, which is nearly hot enough to melt copper. In the first engines, the steam-pipes were brought straight down to the cylinders across the ends of the tubes, but they were found to be very rapidly destroyed.

The area of the large steam-pipe is 19·6 square inches, and is equal to the areas of both the small ones, which are 9·6 square inches each.

The other end of the steam-pipe is connected to the box *a′* (Plate II.) by means of the stuffing-box *b′*, containing packing made of loose-spun hemp, called gasket, compressed against the steam-pipe by the brass gland *c′*, which is bolted to a flanch on the stuffing-box *b′*. This stuffing-box is necessary because iron expands by heat only two-thirds as much as copper, so that when the boiler and its contents are heated, the wrought iron increases in length less than the copper pipe, and the pipe would be very much strained if it were rigidly fixed at both ends, and the joint would soon become defective by the repetition of the action; but the stuffing-box allows the end of the pipe to slide through it, and still keeps the joint steam-tight, preventing all injurious action.[3]

The steam enters through the funnel-shaped copper pipe *d′* (Plate II.), which is fixed upon the top of the box *a′*, and this pipe rises nearly to the top of the steam dome T, which is made of brass, cast three-eighths of an inch thick, and is 15 inches in diameter and 2 feet high, and bolted down by a flanch on to the fire-box. The object of this steam dome, and of carrying the steam-pipe up to the top of it, is to obtain the steam as pure and dry as possible, by taking it at a distance from the water; because from the great agitation of the water in the boiler, and the rapid emission of the steam to the cylinders, some of the water gets mixed up with the steam in a finely divided state, and is liable to pass over with the steam into the cylinders. This effect is called *priming*, and is very injurious when it takes place to any extent, for all the water carried over into the cylinder is wasted, and occupies the place of steam, and thus diminishes the power of the engine; but principally because it accumulates in the cylinder and sometimes remains in it, being unable to escape with the waste steam; and in that case, from being so incompressible, it causes the breaking of some part of the engine. By carrying the steam-pipe up into the dome, the quantity of water taken with the steam is very much diminished, as it has time to separate, and the expanded end of the steam-pipe nearly filling the dome, serves to catch the water and prevent its entering the steam-pipe.

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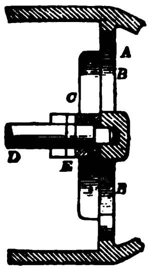
[3] The brass tubes of the boiler are liable to the same action, but as they are small and very firmly fixed at the ends, the expansion is immaterial, the tubes allowing for it by bending slightly.

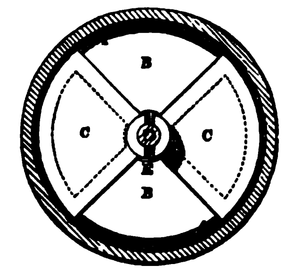
The priming is much increased when the water in the boiler is not clean or pure; and an engine that does not prime perceptibly with good water, may prime very much if supplied with impure or hard water. When priming, the water is thrown out in a shower from the chimney at each blast; and the power of the engine is very much impaired, as the violence of the ebullition of the water is thereby greatly increased. The prevention of the priming was found to be a very great difficulty in the first locomotives, and several contrivances were made use of for the purpose; such as making the steam pass through a plate pierced with holes before entering the steam-pipe, or dividing the dome by a plate, over which the steam had to pass to the steam-pipe. But it has been observed that the priming has been gradually diminished by increasing the steam room, or space in the boiler occupied only by steam; for this renders the generating of the steam more uniform, as the abstraction of the successive cylinders full of steam is less felt, and causes less agitation when the total quantity of steam is greater. In the first locomotives, very little steam room was afforded; but in this engine the steam room is generally about 44 cubic feet, and there is no perceptible priming under ordinary circumstances.

Fig. 11.



**Regulator.**—In the box *a'* (Plates II. and IV.) is placed the regulator *e'*, extending across the box, so that all the steam must pass through it before it can enter the steam-pipe S; and by means of this the steam is either shut off or allowed to enter the steam-pipe in greater or less quantities. The regulator is shown in figs. 11, 12, and 13, to a scale of double the size of the engravings, or 1½ inch to a foot. The box is made of cast iron half an inch thick, and has a plate, A, extending across it, with two openings, B B, of nearly a quadrant each; the diameter of the opening is 8½ inches, and that of the solid part in the centre separating them, 2 inches. The brass plate C, placed against this plate, fits exactly the space between the openings B B, and, if turned round and placed over the openings, would project beyond or overlap them three-quarters of an inch on each side, as they are three-quarters of an inch smaller

Fig. 12.



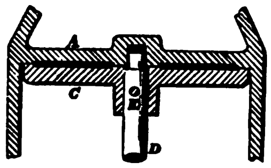


Fig. 13.

than a complete quadrant. The spindle, D, passes through a boss in the centre of the plate C, turning at its end in a socket of the plate A, but without touching the bottom of the socket, and a small pin is fixed into the spindle, fitting into a notch, E, in the centre boss, to enable the spindle to turn round the regulator plate C, and yet allow it to be withdrawn a little without drawing the regulator plate away from the other plate. The plates are held together by the pressure of the steam; and by forming the connection with the spindle in this manner, they are enabled to keep in close contact, although the position of the spindle should be altered, and the regulator plate is still made to turn with the spindle.

The two plates are ground together, so that when the regulator plate is turned round and covers the openings, the passage is closed completely steam-tight; the under side of the regulator plate, and the solid part between the openings in the other plate, are both hollowed a little in the middle, as shown in the section through the centre of each, in fig. 13, so that they touch only for a space of three-quarters of an inch round the edge. This diminishes the labour of grinding them, as there is so much less surface to grind, and also insures their fitting round the edges, where alone it is required; for the little steam that will pass through the hollow between the plates, when the regulator is partially open, is of no consequence, as it will only slightly increase the quantity of steam passing through.

The other end of the box *a* (Plate II.) is fixed by a flanch to the back plate of the fire-box; and an opening is cut in the plate corresponding to the inside of the box, which is closed by a plate having the stuffing-box *f′* fixed on to its inside with its gland *g′*. The spindle of the regulator turns steam-tight in this stuffing-box, a collar on the spindle resting against the end of it; and the handle, *h′*, is fixed on the end of the spindle, moving between two brass arcs, *i′* (Plate II., and fig. 1, Plate IV.), which are connected together at the ends, and bolted on to the fire-box: these arcs serve as guides for the handle when moved, and stop it at each side. In fig. 1, Plate II., the regulator is shown quite open; but if it were made to turn round, it would immediately begin to contract the passage for the steam; and when turned a quarter round, the passage would be completely closed. The motion of the handle is therefore through a quarter of a circle, or half a quadrant on each side of the vertical position. When the handle is put down on the right-hand side, the regulator is shut, and when down on the left side, it is full open; and in intermediate positions the regulator is proportionally fitting in a spiral groove on the spindle, similar to a screw; only that the groove makes but a quarter of a turn round the spindle, and is very much inclined to it, so as to cause the valve to be sufficiently drawn back by a quarter turn of the handle. This regulator is very efficient, and acts a little more uniformly than the other, but the friction in it is greater from the spiral motion, and it is more liable than the other to get out of order and stick fast.

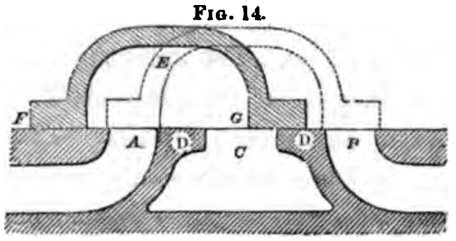
STEAM CHESTS.—The steam chests or slide valve boxes U U, (Plates XC., XCI., and fig. 4, Plate XCII.,) are made of cast iron half an inch thick; and are bolted down upon the top of each cylinder, and to the front plate of the smoke box, in which holes are cut of the same size as the steam chests, and closed by cast iron plates termed bonnets bolted on the outside. The steam chests have the two branches of the steam pipe fixed upon them at the back, and opening into them; and a stuffing box, *k'*, is cast upon the end of each, passing through the tube plate *n*, the joints being completely and firmly closed by running melted lead into it all round.

SLIDE VALVES.—In the steam chests are placed the slide valves, V V, shown in section longitudinally and across in Plate XC., and fig. 4, Plate XCII. They are brass boxes 1½ inch deep inside and three eighths of an inch thick, having flanches five eighths of an inch thick all round them at the bottom. The slide valves are made to move backwards and forwards by the spindles *l'*, which have each a cross piece at the end that fits into a notch in the back of the valve; the spindle is generally connected to the valve by means of a rectangular wrought iron frame, called a bridle, dropped over the valve and having the spindle screwed into it. The bridle has an advantage in holding the valve very steady, and yet allowing it to drop through readily as it is worn by friction, and thus keep always in contact with the surface that it slides upon. The valve spindle *l'* moves steam-tight through the stuffing box *k'* at the inner end of the steam chest.

CYLINDERS AND PISTON.—The cylinders, H H, where motion is produced by the pressure of the steam, are made of cast iron, five eighths of an inch thick and 12 inches diameter inside, and are bored out perfectly smooth and cylindrical. A box is cast on the top of each cylinder, running along its whole length and flat on the upper side, containing two hollow rectangular passages *m'*, *n'*, and another passage *o'*, between them; these are separated from each other, and the ends of them are shown coming to the outside and opening into the steam chest at the left cylinder, (Plate XCI.) The two outer passages *m'*, *n'*, are the steam ports; they are eight inches long and one inch wide, and open one into each extremity of the cylinder, for the purpose of conveying steam to and from the cylinders; their area is 8 square inches, or rather less than the area of the steam pipes. The other passage *o'*, is the waste steam port, of the same length, and one inch and a half wide on the face; expanding inside, as shown in Plate XC., occupying all the space between the steam ports, and passing round the cylinder (as in fig. 4, Plate XCII.) until it clears the steam chest and comes to the outside again opposite to the other cylinder; having gradually assumed a circular form three inches and three quarters in diameter, as shown by the dotted lines in Plate XC. The cross area of this passage is made of such dimensions that although it alters in shape, it is in all parts equal to the area at the end, that of a circle three inches and three quarters diameter or 11 inches area. On the outside of this opening in each cylinder are fixed the two ends of the branching copper pipe *p'*, of the same diameter, termed a breeches piece, and having the blast pipe P bolted on to it. The piece *p'* is fixed on to the cylinders by screws put into holes tapped to receive them in the solid metal, as there is no place for nuts. The steam chest is also fixed on to the cylinder at the hinder end in the same manner. The flanches are made rather thicker to allow for being weakened by the holes in them, and those of the copper pipes are three eighths of an inch thick, and made of brass soldered on to the pipe; the pipes are made of one eighth of an inch sheet copper lapped and soldered at the edges. A layer of canvas or of gasket, like that used for packing, covered with red lead and oil, is placed between the flanches of the pipes and under the flanch of the steam chest, and in all other similar joints, in order to make them steam-tight.

The face of the ports that the slide valve moves upon is made quite even and true by a planing machine, and the valve is ground upon the face to make it fit steam-tight; the face is sunk down round the ports beyond that part over which the slide moves, in order to diminish the surface to be planed and ground. The spaces between each of the steam ports and the waste port, called the bars, are one inch wide. A section of the slide valve, quarter size, is shown in fig. 14, where *A* and *B* are the back and front steam ports, *C* is the waste port, and *DD* the bars. The width of the slide inside is the same as the ports, as shown in fig. 4 (Plate XCII.); the length *E*, (fig. 14,) is one-eighth of an inch less than the distance between the ports, and the flanches *F* and *G* are one-eighth of an inch wider than the ports; so that when the slide is in a central position, as shown by the dotted lines, the flanches *F* and *G* lie exactly over their respective steam ports, and overlap them one-sixteenth of an inch on each side. This overlap is for the purpose of ensuring that one port is completely closed before the other is opened, in order that they may never communicate with each other under the slide during its motion, nor the steam be allowed to enter both ports at the same time.

FIG. 14.



The slide valve is moved backwards and forwards a distance of 3 inches, or $1\frac{1}{2}$ inch on each side of the central position, and is carried beyond the inner edge of each steam port alternately, a distance of nearly half of an inch, as shown in

FIG. 15.

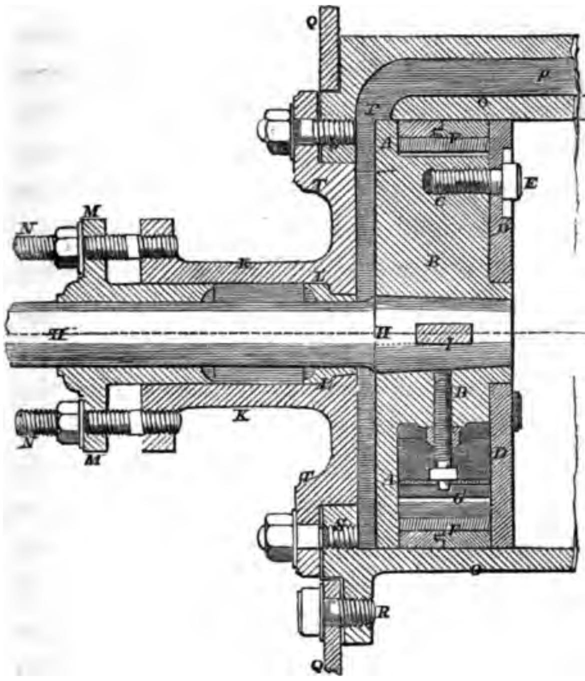
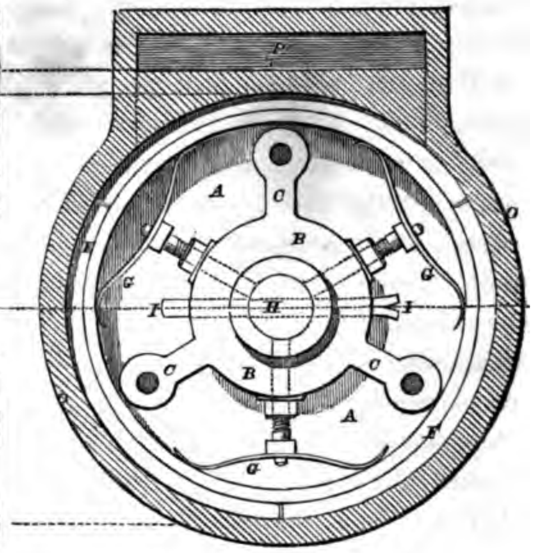


FIG. 16.



the outside; the joints and the space between the flanch and the plate are run with lead all round to make the cylinder quite firm and steady, as the hole in the plate does not accurately fit the cylinder; the joint at the other end of the cylinder is also run flush with lead for the same reason. The flanch is fixed to the plate by six three-quarter inch bolts, which are screwed into the flanch from the outside, in order that they may fit closely to the holes in the flanch and the plate, and hold the cylinder quite steady. A flanch *SS* is cast on the inside of the end of the cylinder, projecting into the cylinder, and the cover *T* is bolted to the outside of this flanch, having a projection in the centre that fills up the opening, and makes the end of the cylinder even or flush inside; the cover is fixed on by six bolts, screwed into the flanch of the cylinder, and having nuts on them on the outside; the bolts are made square where they pass through the cover, to prevent their turning when the nuts are screwed on. It is not required to have ready access to this end of the cylinder; but at the other end it is necessary that there should be no obstruction, as the cylinder is required to be completely opened occasionally to get the piston in and out. *X* (Plate XC.) is one of the pistons; there is one in each cylinder, fitting the cylinders accurately, so as not to let any steam escape between them and the cylinders when they are moved backwards and forwards. The piston is made entirely of brass, and consists of a plate, *A*, (figs. 15 and 16,) five-eighths of an inch thick, having a boss, *B*, cast on the centre, with three arms, *CCC*, three quarters of an inch thick, also cast upon it, radiating from the centre and equidistant from each other.

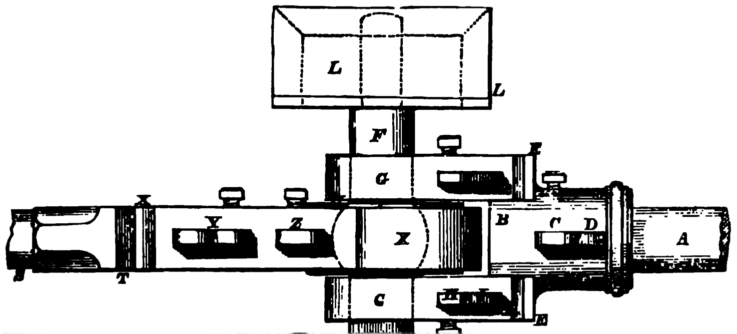
ciple; with two or more rings of cast iron or brass, about an inch thick, cut into three or four segments, and having wedges inserted between them, which are constantly pressed outwards by springs, so as to keep the segments always tight to the cylinder; the springs are either spiral or flat springs like those in the engraving, or a circular steel hoop, a little larger than a circle touching the ends of the wedges, is forced in so as to bear against them. These pistons are liable to a defect from which the other with the spring rings is free; that of wearing grooves in the cylinder where the points of the wedges rub against it, as the wedges have to wear down faster than the segments; the plan shown in the engravings is very efficient, and appears on the whole to be the best. The hemp packing used sometimes in stationary engines is now generally superseded by metallic packing, as it requires frequent renewal, and is unequal in its pressure, the piston having to be packed very tight at first, in order to keep tight for any considerable time; in a locomotive, where the motion of the piston is very rapid, it would be quite inadmissible.

H H, or Y, (Plates XC. and XCI.,) is the piston-rod; it is $1\frac{3}{4}$ inches diameter, and is made conical at the end, being increased to $2\frac{1}{8}$ inches diameter in the centre boss of the piston, which is fitted upon it very exactly, and fixed by the cotter or key I, half an inch thick, and tapered slightly from $1\frac{1}{2}$ inches wide; the piston rod has to be fixed very firmly, and is split at the end, to prevent its getting loose. The other end of the piston rod passes through the stuffing box K, (figs. 15 and 16,) in the cylinder cover; it is made of steel, and turned truly cylindrical, to move through the stuffing box with as little friction as possible. The stuffing box has a half inch space round the piston rod for the packing, which rests against the brass ring or bush L, fitted on to a small flanch at the end of the stuffing box, and is compressed by the brass gland M, which leaves about three inches for the packing. The gland has two projections on the outer end, making an oval shape, and is held by bolts passing through these projections and screwed into corresponding projections on the stuffing box.

The piston is impelled by moving the slide valve from its central position, so as to admit the steam from the steam-chest into the cylinder through one of the ports, as in Plate XC., where the front port *n'* is shewn open; and the steam pressing against the front of the piston impels it to the back end of the cylinder. The slide is then moved to the opposite position, covering over the front port *n'*, and opening the back port *m'*, to admit the steam behind the piston and impel it back again to the fore end of the cylinder; at the same time allowing the steam in front of the piston, which had impelled it before to the back of the cylinder, and is now waste steam, to escape by the inside of the slide and the waste port *o'*, into the blast pipe, rushing each end, a branch from the waste port being brought up alongside of them corresponding in size and distance with the present one, and a separate slide placed over each port. The action of the steam in this arrangement was exactly the same as in the present one, but the quantity of steam wasted in the ports was much diminished. Double slides were used in several of the first locomotives, but they have since been abandoned; as the quantity of steam contained in the ports is but small compared with the contents of the cylinder, and the arrangement added considerably to the friction and the complexity of the machine. However, in all stationary engines, except some of the smallest, double slides are used, but they are generally of a different construction and made together in one piece.

Cross-heads and Guides.—The outer end of the piston rod Y is attached to the cross head Z, (Plates XC., and XCI.,) shewn on a large scale in figs. 17, 18, and 19, which are drawn three times larger than the engraving, or to a scale of 2½ inches to a foot. Fig. 17, is a plan; one side being shewn broken off, as it is exactly like the other side; fig. 18, is a longitudinal section through the centre; and fig. 19, a cross section shown complete on both sides. The end of the piston-rod *A A* is turned down smaller, and fitted into the wrought iron socket *B B* by the key or cotter and gib *C* and *D*; the gib *D* being tapered like the key, making their outer edges parallel. Two arms, *E E*, project from the end of the socket *B*, parallel to

FIG. 17.



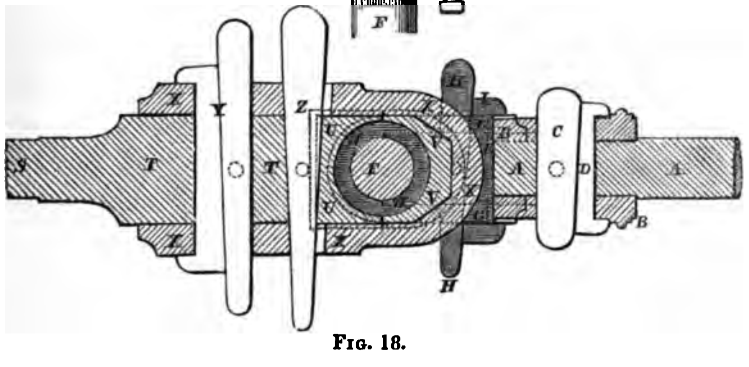
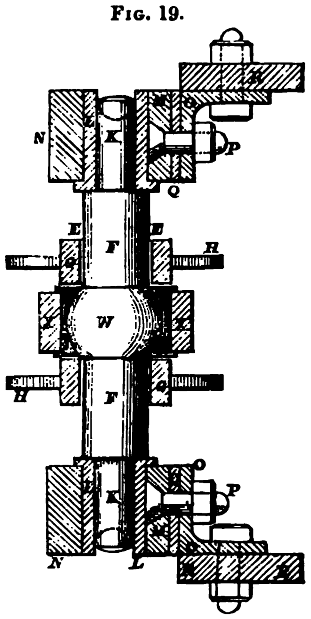


FIG. 18.

FIG. 19.



each other, having a semicircular notch at the end fitted exactly to the cross head *F*, which is a turned iron pin, one inch and three-quarters in diameter. The cross head *F* is attached to the arms *E E*, of the socket *B B*, by wrought iron straps, *G G*, fitted on to both, and fixed by the keys and gibs *H* and *I*; the gibs being required to prevent the ends of the straps being sprung open by driving the keys. A small projection upon the cross head is fitted into a notch in one of the arms, *D*, in order to prevent its turning round.

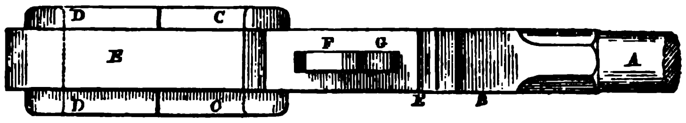
The ends of the cross head *K K* are inserted into two guide blocks, *L L*, 6 inches long and 1¾ inch thick, with flanches on the inner side; these are made of steel and are grooved on the sides to save metal. Each of these guide blocks is placed between two steel bars, *M N*, 2½ inches wide, fixed firmly to the frame of the engine, and shewn at A′ A′, in Plates XC. and XCI. The guide blocks and bars are ground together and fitted accurately, enabling the blocks to slide steadily and easily between the bars; the upper bar, *M*, is five-eighths of an inch thick, and the lower one, *N*, one inch thick in the middle, and five-eighths of an inch at the ends; the two being connected firmly together by small pillars, *c*′, (Plate XC.,) fixed into them at each end. The lower bar, *N*, is required to be stronger than the upper one, as it is only supported at the ends. The upper bar, *M*, is fixed to a piece of angle iron, *O*, (fig. 19,) by bolts *P*, with countersunk heads, ground down flush with the bar; small pieces of brass, *Q*, being interposed between the bar and the angle iron at each of the bolts, affording the means of adjusting the bars accurately level when the angle iron *O* is fixed on to the engine framing *R*. The bars *M N* are adjusted exactly parallel to each other, and to the axis of the cylinder, so as to allow the blocks, *L*, to slide behind them without any strain when moved by the piston rod and cross head; and they serve the purpose of guiding the end of the piston rod, and causing it to move always exactly in the line of the axis of the cylinder.

Connecting Rods.—The connecting rods B′ B′, (Plates XC. and XCI.,) are fixed at one end to the cross heads, and at the other end to cranks on the axle, C′ C′, of the large wheels, D′ D′, of the engine; they are of wrought iron, two inches diameter in the middle, and taper down to one inch and five-eighths towards the ends. The manner of fixing them to the cross heads, is shewn in figs. 17, 18, and 19, *S* being the end of the connecting rod, enlarged at *T T* to three inches wide, and made square and flat at the end. The brass bearing, *U*, is fitted to the end, and has another brass piece, *V*, upon it, made octagonal on the back; the two brasses are two inches wide, and have flanches upon them at the sides, as shewn by the dotted lines in fig. 18, that of the end brass *V* being semicircular.

The brasses are fitted accurately on to a spherical ball, *W*, that is turned upon the middle of the cross head, and are held upon the end of the connecting rod, *T*, by the iron strap, *X*, fitted between the flanches of the brasses and fixed to the connecting rod by the key and gib *Y*, so as to hold them firmly and steadily together. The key *Z* is put through the connecting rod and strap close to the inner brass *U;* the holes in the strap being made larger than the key at the outer end, so that the key bears against the brass *U*, and forces it against the brass on the cross head. The connecting rod moves upon the cross head, and the friction causes the brasses to wear, so that they require tightening up occasionally by driving in the key *Z* farther, and bringing them nearer together; a little space is left between the brasses to allow for this. Small screws are inserted opposite to each of the keys, and are screwed against them when they are driven into their places to prevent their jolting loose.

The construction of the other end of the connecting rod is shewn on the same scale in figs. 20 and 21, which are a plan and a longitudinal section of it.

Fig. 20.



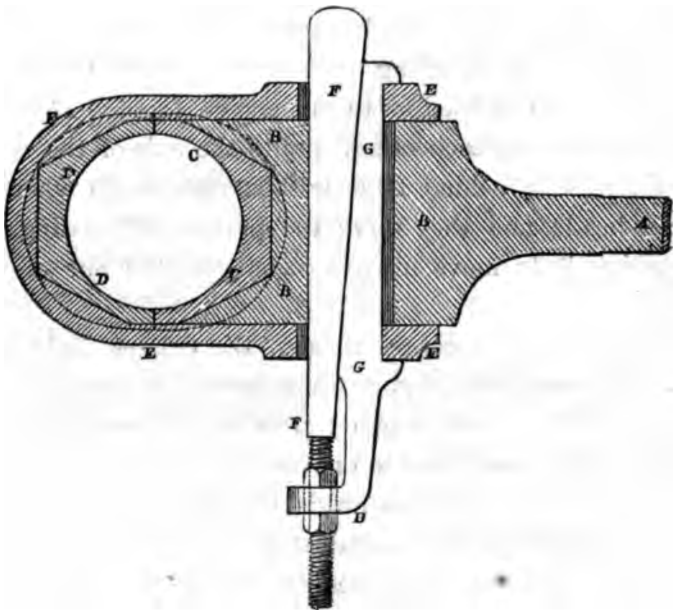
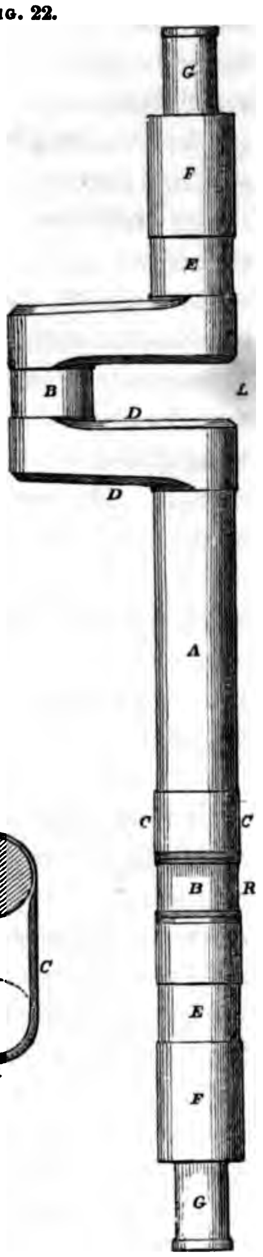


Fig. 21.

*A* is the end of the connecting rod, which is enlarged at *B B* to five inches and three quarters wide, and cut out to an octagonal shape at the end, fitting the brass bearing *C*. The other brass, *D*, is similar to it, and they are both three inches wide, with semicircular flanches on the outside to hold them steady; and are fitted on to the crank pin, which is cylindrical, and five inches' diameter, as shewn by the dotted lines in fig. 20, and rounded out to a shoulder on each side. The brasses are held by the strap *E*, which is fixed on to the end of the connecting rod by the key *F* and gib *G*; the key terminates at the bottom in a screw passing through the prolonged end, *H*, of the gib, and held by nuts. These nuts are screwed up against the end of the gib, when the key is driven into its place; and effectually prevent its jolting loose; the hole for the screw being made oblong, to allow for the side motion of the key. The holes in the strap *E*, for the key, are made rather longer outwards than the key, and the key-way in the connecting rod is as much longer at the inner end; causing the key to bear only against the connecting rod, and the gib against the strap: the strap is thus drawn farther on the connecting rod by driving the key, and the brasses are brought nearer together, and tightened up on the crank pin as they are worn by friction. This end of the connecting rod is shortened as much as the brasses wear, as the outer brass is drawn inwards by the key; but the other end of the connecting rod is lengthened by the wear of the brasses, because the outer brass is fixed, and the inner one is pressed against it by the key. The total length of the connecting rod is thus kept always nearly the same, as the wear of one set of brasses compensates for that of the other. If this were not the case, the piston would be brought nearer to one end of the cylinder than the other by the wear of the brasses, and would require more clearance, to prevent it striking the cylinder cover.

CRANKED AXLE.—The axle C′ of the large wheels D′, (Plate XC. and XCI.,) is called the cranked axle, from its having two cranks in it, to which the connecting rods from the two pistons are attached. It is drawn to a scale of an inch to a foot, or one third larger than the engravings in figs. 22 and 23, and it is shewn in the same position as in the Plates. It is made all in one piece and of the best wrought iron, termed back-barrow, or scrap-iron, and is 6½ feet long, and 5 inches in diameter. The axle is cylindrical at the centre part, *A*, (fig. 22,) and is increased to five and a quarter inches at *C C*, where the cranks are formed. The two cranks, *R* and *L*, for the right and left hand cylinders, are exactly at right angles to each other, as shewn in fig. 23, which is a section through the axle at *E*; the sides of the cranks *D D* are four inches thick. The crank pins *B B* are five inches diameter and three inches long, the same dimensions as the brasses in the ends of the connecting rods, which are fixed upon them; and the length of the cranks from the centre of the axle to the centre of the crank pin is nine inches, which is exactly half of the stroke of the piston. Upon the parts *F F*, which are seven and a half inches long, the wheels are firmly fixed, so as to prevent their turning or shaking upon the axle; and outside the wheels, at *G G*, the axle is reduced to three inches and an eighth diameter for five inches in length, having a collar at the end; these parts, *G G,* turn in brasses, which are fixed in the outside frame of the engine, and have the weight of the engine resting upon them. The axle is all turned in a lathe, and each of the crank pins is also turned by suspending the axle on centres corresponding with the centre of the crank pins; and made in strong cast iron arms, that are firmly fixed on the ends of the axle, and project beyond the cranks, so as to balance the axle, and enable it to turn round on the centre line of the crank pin. The axle is by this means made very true, and the cranks are made of exactly the proper length, and at right angles to each other. The corners of the cranks are champered off, as shewn in the figure, and the ends of the smaller cylindrical parts well rounded out.

Fig. 22.



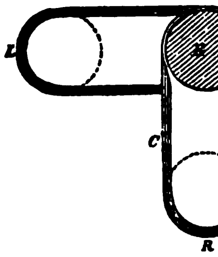


Fig. 23.

The crank *R* of the right hand cylinder is shewn vertically, and in its lowest position; and the piston in the cylinder is shewn in the middle of its stroke, or at half stroke. (See Plate XC.) If the piston be now made to move backwards, by admitting the steam to the front of it, it will press against the crank pin by means of the piston rod and connecting rod, with a force equal to the pressure of the steam upon it; and as the piston is twelve inches diameter, or 113 square inches area, this force upon the crank will be 2½ tons, when the steam is at the usual pressure of 50 lbs. per square inch. And as the cylinder and cranked axle are firmly connected together by the framework of the engine, they cannot be separated by this force upon the crank; the crank therefore gives way by turning round, making the axle and wheels upon it revolve in the direction of the arrow, until it is brought to its farthest position and becomes horizontal, as the left hand cylinder is shewn in Plates XC. and XCI., and the piston has arrived at the end of its stroke.

On reversing the slide valve to admit the steam behind the piston, and produce a fore stroke, the piston has no power to move the crank, as it is pulling directly in a line with the centre of the axle, and only tending to break the axle; and the crank has therefore to be moved on, so as to rise a little above the centre line, when the piston is able to move it, and pulls it round to the opposite position, or the side next the cylinder, and the piston arrives at the end of its stroke. On the commencement of a back stroke the piston has also no power to move the crank, it being again on the centre, and requiring to be assisted on a little, to enable the piston to act upon it and push it round to the opposite side again. The crank requires assisting over these two centres, or dead points, in order that continued rotation may be produced by the reciprocation of the piston; and for this purpose the two cranks upon the axle, which are worked by the two pistons, are placed at right angles to each other: for when one of the cranks is on the centre, and the piston connected with it has no power to make it revolve, as is the case with the left hand crank in Plates XC. and XCI., the other is at half stroke, and its piston has the greatest power upon it, so that it moves the axle round and makes the other crank pass the centre. In a similar manner, when they have made a quarter revolution, the right hand crank comes to the centre, but the piston of the left crank is then in full action, and this continues throughout the revolution, one crank being always in full action, when the other comes to the centre and ceases to propel the axle.

The power of the piston to propel the crank is greatest at half stroke, when the connecting rod is at right angles to the crank, and acts with the leverage of the full length of the crank; but as the piston advances to the end of the stroke, the angle that the connecting rod forms with the crank is continually diminishing, and with it the leverage and power to propel the crank, until at the end of the stroke the crank comes to the centre, and the connecting rod ceases to have any power to move it; the mean leverage throughout the stroke being only about two thirds of the length of the crank. This would cause therefore the motion to be very irregular if there were only one crank; but with two cranks placed at right angles to each other, the irregularity is very nearly corrected; as at half stroke the power of one piston only is effective, and at quarter stroke the power of both pistons together, though acting with equal advantage, very little exceeds the full power of the one alone. In stationary engines which have only one cylinder, the irregularity of the action of the crank is compensated for by the use of a large and heavy fly-wheel; which when once set moving, has sufficient momentum to bring the crank over the centre, and to render the velocity of the motion very uniform, as there is not time to accelerate its velocity perceptibly in the middle of the stroke, or to diminish it at the ends. Marine engines which have no fly-wheels are always in pairs, like locomotives, except in some of the smallest vessels.

The connecting rod being inclined below the piston rod during the back stroke, and above it in the fore stroke, requires a moving joint at the end which takes hold of the cross head; and the cross head is made spherical at that part, to prevent any lateral strain that might arise during the motion from the crank not being accurately in the line of the piston rod, or the axle at right angles to it. The varying position of the connecting rod also renders the guides for the piston rod necessary to resist the great oblique strain upon it caused by the inclined positions of the connecting rod tending to force it upwards in the back stroke, and in the opposite direction during the fore stroke. This oblique strain is diminished by increasing the length of the connecting rod; which is therefore made as long as possible, in order to diminish the friction of the guide blocks, leaving only a small clearance beyond the crank and head of the piston rod at their extreme positions. Other modifications of the plan are also used to preserve the parallel motion of the piston rod, such as a single square bar placed on each side with the edges at top, termed diamond guides, and having sockets on the ends of the cross heads sliding upon them; but the other plan is found to be most advantageous; in small stationary engines similar plans are also sometimes adopted. But in stationary and marine engines generally, the motion of the piston is maintained in a straight line by various combinations of rods, forming a parallel motion, which has less friction than guides, and is more convenient in those cases. The strain is also diminished by the piston rod being connected with the end of a beam instead of directly with the connecting rod, which has a much less irregular motion.

The two cranks are thus made to revolve uniformly by the action of the steam upon the pistons in the cylinders, and move with them the axle and the wheels fixed upon it. The wheels are made to revolve in the same direction that they would turn if the engine were running forward; and they cannot turn round without either slipping round upon the rails, or rolling forward upon them and moving the engine with them. If the adhesion of the wheels upon the rails is greater than the resistance of the engine to being moved, and the pressure of the steam be sufficient, the wheels will roll forward upon the rails; and the engine will be propelled, and be able to draw after it a load, the resistance of which is equal to the excess of the adhesion of the wheels upon the rails above what is required for moving the engine itself. The adhesion of the wheels is not always the same; it is the greatest when the rails are most clean, and are either quite dry or quite wet; and it is least when the rails are dirty, and greasy with being partially wetted. For this reason an engine, which is not loaded so much as the full adhesion of the wheels upon the rails, will often slip, and let the wheels turn round quicker than the engine is running, on passing a station, or any part of the line where the rails are liable to be dirtied by the traffic of persons across them.

The adhesion of the wheels is found to be about one fifth of the weight upon them when the rails are in a good state, and it varies between that and one tenth or twelfth. The weight upon the driving wheels as they are termed, is six tons, and the adhesion is therefore sufficient for drawing a load of 280 tons besides the engine upon a level. When the first locomotives were made, it was thought that the adhesion of the wheels upon the rails could not be sufficient to draw any load besides the engine, if it were enough for that; and various contrivances were resorted to, in order to obtain the necessary fulcrum from which to move the engine. Levers were first tried which resembled a horse's legs, and were thrust against the ground by the piston rods; a chain was also tried lying on the ground between the rails and taken hold of by a wheel in the engine; also a rack was fixed inside the rails and a toothed wheel turned by the engine worked in it. Locomotives which are intended for conveying heavy goods have their adhesion upon the rails generally increased by coupling four wheels together so as to make them all turn together, and thus obtaining the adhesion of all the four to assist in drawing the load. The power of the engine can then be increased as the increased adhesion will enable it to be exerted; for the power of engines with only two driving wheels cannot exceed a certain limit, or it will be greater than the adhesion of the wheels and the excess will be useless. The wheels that are coupled together are of the same diameter, and have connecting rods attached to cranks, which are fixed on the axles outside of the wheels. Some of the old engines had their wheels coupled by a pair of cog wheels; and also by an endless chain passed round a pulley on each axle.

The plan of driving the wheels of a locomotive by means of cranks upon the axle, is attended by the disadvantages that the axle is weakened very much by the cranks in it, and the power is applied at some distance from the wheels where it is wanted. The action of the pistons upon the cranks, alternately pulling and pushing them, and the great weight that the cranked axle has to carry, make it necessary that it should be made very strong in order to stand its work; they are therefore very heavy and expensive, costing about £50 each. They are very seldom broken, though they sometimes get bent by the engine running off the line; but the older locomotives had their cranked axles broken more frequently, as they were not made so strong at first. Several plans have been tried for obviating the necessity for a cranked axle, but they do not appear to be any of them so good upon the whole. The Rocket, and some of the first locomotives upon the Liverpool and Manchester Railway, had their cylinders placed outside and fixed above the wheels; and the connecting rods took hold of crank pins outside of the wheels and fixed into them, so as to drive them directly. But it was found better afterwards to place the cylinders in the smoke box, where they were protected from the air, which cooled them very much before; and the machinery could then be fixed more conveniently; some engines, however, are still made on that construction. Engines have also been made with vertical cylinders, which worked cranks outside the wheels by means of bell cranks and connecting rods.

FIG. 25.

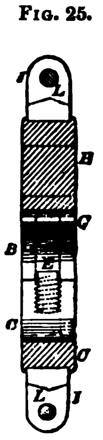
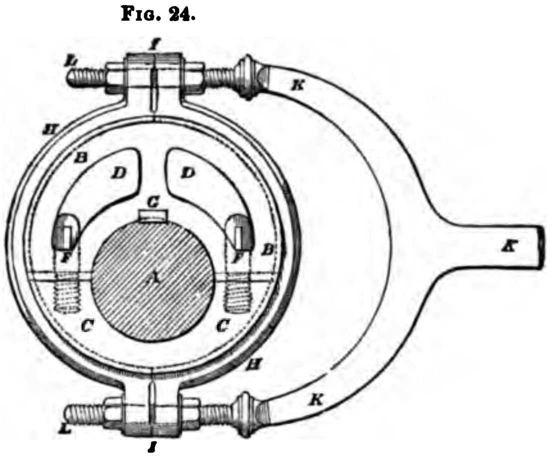


FIG. 24.



ECCENTRICS.—Upon the cranked axle C′, (Plates XC. and XCI.,) are fixed the four eccentrics E′, E″, F′, F″, for the purpose of working the slide valves. The construction of one of the eccentrics is shewn to double the scale in figs. 24 and 25, which are drawn to a scale of an inch and a half to a foot. Fig. 24 is a side elevation of an eccentric, and fig. 25 a section through the centre of it. *A* is a portion of the cranked axle, five inches diameter; *B* and *C* are two cast iron pieces, two inches and a quarter wide, forming the eccentric, and each fitted half round the axle; the smaller one, *C*, being one inch thick in the middle, and the two pieces forming together a circle of ten inches diameter. They have a projection of a quarter of an inch running round both sides of the outer edge, and the piece *B* has two openings, *D D*, cast in it to diminish the metal, leaving a thickness of an inch on each side. A rebate, *E*, projects from the straight edge of the piece *C*, fitting into a groove in *B* to hold them steadily on each other; and the two pieces *B* and *C* are fixed together by the pins *F F*, which are firmly screwed into the piece *C*, and passing through corresponding holes in the other piece into the openings *D D*, are fixed by keys driven through them; the whole eccentric is then fixed upon the axle, so as to make them turn round together by driving the key *G* into a groove in both. The brass ring *H H*, one inch thick in the middle, is put in the groove round the eccentric; being made in two pieces in order to enable it to be put into the groove, and the ends connected by flanches *I I*. *K K* is the eccentric rod, forked at the end; the ends of the fork being three-quarter inch screws, which pass through the flanches of the brass rings *H*, and hold them together by nuts upon the screws. The other ends of the eccentric rods *e″ e‴* and *f″ f‴*, (Plates XC. and XCI.,) are carried on towards the smoke box; and when the axle $A$ revolves, the eccentric $B\,C$ revolving with it, turns round inside of the brass ring $H\,H$, which is prevented from revolving by the eccentric rod that is fixed to it. The groove of the eccentric and the brass ring are both turned exactly to fit, allowing the eccentric to turn freely and steadily within the ring. As the eccentric projects from the axle more on one side than the other, the ring is pushed out farther from the axle on that side; and in revolving with the axle, the ring is pushed out from the axle on each side in succession, causing the eccentric rod to be moved in each direction from its central position as much as the projection or the eccentricity, which is an inch and a half, or three inches total motion or throw.

The action of the eccentric is precisely similar to that of a crank an inch and a half long; and the eccentric is in fact a crank with a very large crank pin, this pin being ten inches in diameter, and reaching beyond the axle itself; and the eccentrics are used instead of cranks, to avoid the necessity of making so many small cranks in the axle, though there is considerable loss of power attending the use of them from the friction being increased by their large size. Eccentrics are used for working the slide valves in almost all steam engines, because of their convenience and steady action; they are also readily capable of adjustment, by altering the position in which they are keyed on the axle. They cannot be cast in one piece as the cranks are forged with the axle, and the eccentrics have, therefore, to be put on in two halves.

SLIDE-VALVE GEAR.—A side elevation of the eccentric rods and levers for working the slides is shewn detached in figs. 2 and 3, (Plate XCI.,) in two different positions, with a cross section through the eccentric rods, shewing a back elevation of the levers, &c., in fig. 4; and a plan of them is given in Plate XCI., in their position in the engine. The two eccentrics E′ and E″, are for working the slides when the engine is running forward; E′ being for the slide of the right hand cylinder, and E″ for that of the left cylinder, and the ends of the eccentric rods, $e'' \; e'''$, are formed into large vertical forks, $g'' \; g'''$, having a notch in the bottom of each; the section in fig. 4 (Plate XCI.) is taken through the notches. These notches take hold of steel pins, with shoulders to hold the eccentric rod steadily, which are fixed into the lower ends of the levers $h'' \; h'''$, by means of nuts screwed on at the other side. The levers $h'' \; h'''$ are keyed on to the ends of the horizontal shafts or weigh-bars $i'' \; i'''$, turning in brass carriages, $k'' \; k'''$, fixed on to the frame of the engine, and made in two pieces, the upper part being loose and held down upon the weigh-bar by bolts, allowing it to be tightened up as it wears. Upon the weigh-bars $i'' \; i'''$, and standing above, are fixed the levers $l'' \; l'''$, of the same length as the bottom levers, $h'' \; h'''$; and two horizontal links, $m'' \; m'''$, are attached to the ends of each of these levers by a steel pin passed through them, with a small pin and washer at the end, to prevent its getting loose; the other ends of the links $m'' m'''$, being attached in a similar manner to a socket on the valve spindle $l'$, which is guided at its end by an eye in a small pillar fixed on to the boiler.

The eccentric rods $e'' e'''$, taking hold of the bottom levers $h'' h'''$, make them move backwards and forwards with the eccentrics; and the top levers $l'' l'''$, connected with them by the weigh-bars $i'' i'''$, communicate the motion to the valve spindles by means of the links, $m'' m'''$; the levers $h''$ and $l''$ being of the same length, the motion of the slide valves is the same as the throw of the eccentrics, or three inches, as before stated. The links allow for the oblique action of the top levers which move in an arc of a circle, instead of a straight line as the valve spindle. The pins and eyes of the levers are all of steel, to diminish the wear, and are fitted very accurately, so as not to allow any shake when the motion is rapidly reversed at the end of each stroke, and that the slide may be moved the full three inches. The eccentrics $E'$ and $E''$ are placed at right angles to each other, that they may be both in the same relative position to the respective cranks; and they are fixed in such a position with regard to the crank, that the port is full open, or the slide at the end of its motion, when the piston is at half stroke, as shewn in Plate XC. The eccentrics are therefore at right angles to their respective cranks, and they have to be fixed a quarter of a revolution behind the cranks, in order to move the slides as much in advance of the pistons; because the levers $h''$ and $l''$ reverse the motion, so that when the slide has to be pulled back, the eccentric rod must be pushed forward.

Reversing Gear.—The eccentrics, $E'$ $E''$, are placed so as to work the engine forward; and when the crank is down, as in Plate XC., to cause the piston to be pushed back, and pulled forward when above the axle, and thus cause the wheels to turn round in the direction of the arrow, and propel the engine forward. In order to make the engine run in the opposite direction, two other eccentrics, $F'$ and $F''$, are necessary, which are placed exactly in opposite directions to the former ones, or at the extreme back position when the former ones are at their greatest throw forward; their rods, $f'' f'''$, have forks at the ends, similar to the other eccentric rods, and levers, $n'' n'''$, corresponding to them are fixed on the other ends of the weigh-bars $i'' i'''$, exactly like the levers $h'' h'''$. The four eccentric rods have pins fixed into them below the forks, and attached to the suspending rods, $o'' o''$, $o''' o'''$; the two middle rods, $o'' o''$, for the working eccentrics, $E' E'$, being connected at the top to a cross head at the end of the horizontal lever $p''$, and the other two, $o''' o'''$, for the reversing eccentrics, forked at the top, and attached to the levers $p''' p'''$, which extend in the opposite direction to the lever $p''$. The lever, $p''$, is keyed upon the cross shaft $q''$, and the other two, $p''' p'''$, upon another shaft $q'''$, both extending to the side of the engine, and turning in carriages, like the weigh bars $i'' i'''$, and having the vertical levers $r'' r'''$ fixed upon their outer ends. The levers $r'' r'''$ are connected by the link $s''$ attached to both; and one of them, $r''$, extends above the joint, and is attached to the end of the long bar $t''$, extending to the back of the engine, and connected to a similar lever, $u''$, upon a short shaft, $v''$, which is fixed on the frame at the side of the fire-box. On the outer end of this shaft, $v''$, and close to the hand railing of the engine, is fixed the long handle $w''$, which moves between guide plates attached to the hand rail; the outer guide having a notch in the middle to hold the lever $w''$ in a vertical position, and another at each extremity of the passage between the guide plates.

In Plates LXXXIX., XC., and figs. 1, 3, and 4, Plate XCI., the lever $w''$ is shewn pushed over into the forward notch, pulling the levers $r'' r'''$ forward also, by the bar $t''$ and link $s''$; causing the lever $p''$ to be raised by the means of the cross shaft $q''$, and to pull up the ends of the eccentric rods $e'' e'''$, by the suspending rods $o'' o''$, making the notches in them take hold of the pins in the bottom levers, $h'' h'''$, of the weigh-bar. The two forward working eccentrics, $E' E''$, are thus put into gear, and made to work the slides of the two cylinders, and cause the engine to be propelled forwards. The other two lifting levers, $p''' p'''$, are at the same time lowered by the lever $r'''$ being pulled forward, letting down the rods $f'' f'''$ of the reversing eccentrics by the suspending rods $o''' o'''$, so that their forks clear entirely the pins in the levers, $n'' n'''$; leaving them free to move with the weigh-bar, and in exactly opposite directions to the eccentric rods $f'' f'''$ below them.

When the hand lever $w''$ is placed in the centre notch of the guides, or in a vertical position, as shown in fig. 2, (Plate XCI.,) the side levers $r'' r'''$ are brought upright, and the lifting levers $p'' p''' p'''$ made horizontal; so that the ends of the middle eccentric rods are let down, and the notches in them escape from the pins in the bottom levers of the weigh-bars: and the outside eccentric rods, $f' f''$, are only raised into a similar position, and are still not in contact with the levers of the weigh-bars. The slides will therefore cease to be worked, although the eccentric rods continue moving, and the engine will not be propelled any more, as the steam continues pressing upon the same side of the pistons.

But when the hand lever $w''$ is pulled quite over into the back notch of the guides, the positions of the eccentric rods are reversed; the outside lifting levers, $p'' p''$, being raised into the same position that the other lever, $p'$, had before, and drawing up the ends of the rods $f'' f''$ of the reversing eccentrics $F' F''$, to catch the pins in the levers $n'' n'''$ of the weigh-bar upon one of the inclined planes of their forks, and force them into the notches in the bottom of the forks. The reversing eccentrics, $F' F''$, are thus brought into gear, and made to work the slides, causing the motion of the pistons to be reversed by the steam being admitted on the opposite side of them, and making the engine run in the opposite direction to its former course; the middle eccentric rods, $e'' e'''$, are at the same time lowered, as the outside ones were before, allowing the forks upon them to clear the pins of the levers $h'' h'''$. The engine can then be propelled forward again by putting the hand lever over into its front position; dropping the rods of the outer reversing eccentrics out of gear, and drawing up the inner rods of the forward working eccentrics to force the levers of the weigh-bars into the opposite positions by their forks, and take hold of the pins in them.

The engine can thus be made to run either forward or backward, by merely pulling the hand lever $w''$ forward or back; and the handle is placed close to the engine man, who stands behind the fire-box, so as to be readily moved; it is fixed so as to drop into the notches, and requires pulling out of them to shift its position, in order to prevent its jolting loose. The suspending rods, $o'' o'''$, that support the ends of the eccentric rods, have to be moved with the eccentric rods in working, causing some friction to the engine; those rods that are in gear have to be held close up to the pins on the levers of the weigh-bars, that they may not get out of the notches in the eccentric rods; and their motion does not exactly correspond with that of the pins in the levers of the weigh-bars, from the suspending rods taking hold below the notches of the eccentric rods, and moving in an arc of a rather larger circle, causing a little additional friction from the sliding of the pins in the notches, though the amount of it is very small. To obviate this, the eccentric rods are placed in some engines above the pins in the levers of the weigh-bars, with the forks and notches inverted, so as to drop down upon the pins and rest upon them when in gear; allowing the suspending rods to have a loose hold of them, as they do not require support. This plan is liable to the objection, that if the eccentric rods should accidentally get loose by the pins jolting out, they would all fall into gear and cause the breaking of the machinery, as they move in opposite directions; but with the other arrangement the eccentric rods would in this case merely fall upon a rod that is fixed under them across the engine.

This plan of reversing has been but lately introduced, having been first used by Messrs. Stephenson, and since adopted with different modifications by other makers. The plan in many locomotives is, to have the four eccentric rods suspended above the levers of the weigh-bars in a similar manner to the last, but with notches only in their under side, so that they cannot take hold of the lever pins until they have moved along, and the notches coincide with the pins; the slides and levers being moved to the right position by means of two starting handles fixed on to the fire-box, and connected by rods and levers with the two weigh-bars, and these starting levers are always moving with the slides. This plan is inferior to the other with the forked eccentric rods, as the slides have to be set by the starting handles, as well as the eccentrics reversed, in order to reverse the engine; though when the engine is running, the first is not required, but a considerable strain is then caused by the eccentric rods suddenly catching hold of the pins and bringing them into motion. The starting handles are used to enable the engine to be moved very steadily or for a small distance by working the slides by hand, the eccentrics being thrown out of gear; but a good regulator renders them unnecessary for this purpose, as the steam can be admitted very gradually to the cylinders. Considerable friction is also caused by their being continually in motion with the slides, and to avoid this, another handle has been added in some cases, by means of which they can be thrown out of gear when not required; but that adds to the complexity.

The plan of driving the slides that has hitherto been most universally adopted, and is still much used, is by means of two eccentrics only, fixed together at right angles to each other, and placed loose upon the centre of the cranked axle; their rods being connected with the weigh-bars, as in the other plans; and a driver with a projecting stud is fixed on the axle on each side, just clearing the eccentrics, a hole being made in each side of the eccentrics to fit the studs. The eccentrics can be shifted along the axle to either side by means of a lever, to make the stud in the driver on that side drop into the hole in the eccentric when it comes opposite to it in revolving, and cause the eccentric to turn with the axle and work the slides. The stud of the other driver is put on the opposite side of the axle to the corresponding hole in the eccentric; so that when the eccentrics are shifted to the other side by the lever, they have to stop for half a revolution before that driver catches hold of them, and are then fixed exactly opposite to their former position, and reverse the engine; in their intermediate position, when they touch neither of the drivers, they are stationary and cease to work the slides. This plan is inferior to those with four eccentrics, as it is not so certain in its action, and does not keep in order so well.

Working of Slides and Piston.—As the slides are worked by eccentrics, they are not suddenly reversed in position at the end of each stroke, in order to let the steam on to the other side of the piston, and keep the steam port full open throughout the stroke; but are always in motion, and commence returning as soon as they have arrived at the end of their stroke. From this cause they are obliged to have some travel, in order that the port may be full open for some time; and after having fully uncovered the port, the slides move or travel a little farther, not beginning to close the port again until they have returned over the travel. The motion is very varying as the eccentric drives the slide most quickly at the middle of its stroke; corresponding to the ends of the strokes of the piston, where the quickest motion is wanted, to admit the steam for the next stroke; the velocity of the slide diminishing rapidly towards the ends of its stroke, where it stops and retrogrades. Many contrivances have been tried in stationary engines for working the slides more suddenly, either by striking the spindle with tappets or projections on a moving rod, or by means of different kinds of cams or eccentrics of irregular shapes; with these plans travel of the slide would not be necessary, the port being full open nearly all the stroke. But in a locomotive no plan can well be adopted for working the slides which has a more sudden or irregular motion than an eccentric, because of the very great rapidity with which the strokes have to be made; which would soon cause the machinery to be deranged.

The piston and slides make two reciprocations or changes of motion during one revolution of the driving wheels, and as these are five feet in diameter, they make nearly 4 reciprocations per second when the engine is running at the rate of 20 miles an hour, and 8 reciprocations in a second when running at a little more than 40 miles an hour; the ordinary rate of working is about five reciprocations per second. This extreme rapidity causes every change of motion to produce a violent blow to the machinery, requiring that all the parts should be very well made and fitted together, in order that they may stand the work; the greatest strain is produced upon the fixing of the piston rod into the piston, and upon the joints of the piston rod and connecting rod. The brasses in the crank end of the connecting rod are not keyed up quite tight, but a very little play is left, allowing them just to shake when worked backwards and forwards; in order to prevent their heating by the great rapidity of the motion, and expanding by the heat together with the crank pin, making the joint very tight; they have sometimes expanded so much from the heating in consequence of being keyed too tight, that the engine has been nearly stopped by the great friction occasioned, and the brasses have been broken to pieces.

All the moving parts require a constant supply of oil to diminish the friction; and oil cups are fixed for this purpose upon all the principal moving parts, such as on the ends of the connecting rods over the bearings, on each of the piston rod guides, and over the piston rod and the slide valve spindle; the piston is oiled by pouring oil into the cylinder by the cock in the cylinder cover, the bent end of the cock turning round for the purpose. An oil cup is shown one quarter the full size in figs. 26, 27, and 28. Fig. 26 is a side elevation of it; fig. 27, a section through the centre; and fig. 28, a plan of the top. The cup *A* is made of brass, and the cover *B* has a piece projecting from it turning upon a pin in a socket *C* at the side of the cup *A*, and square at the end, resting upon a small spring at the bottom of the socket to hold it either open or shut. An iron tube *D*, is fixed into the foot of the cup, extending to the top, and projecting through the bottom, where it is screwed, for the purpose of fixing the cup on to the part which has to be oiled. The hole into which the cup is screwed runs through to the rubbing surface; and some cotton thread is put through the tube, dipping into the oil in the cup, and the other end touching the moving part; the thread acts as a syphon, and continually drops the oil upon the rubbing surface. The oil cups were made at first without the tube or cotton thread, but the oil was found to run out too quickly, and could not be kept supplied; loose cotton was then put into the cup to prevent the oil running out so fast, but the syphon cup acts much better as it supplies the oil uniformly and gradually. The oil cup on the crank end of the connecting rod has so violent a motion, that it is almost impossible to keep the cover shut without the spring is very strong; the covers are sometimes detached and screwed on, but they are then very liable to be lost; and the best cup for that purpose is one without a loose cover, but with only a small hole in the top to pour in the oil, and made funnel-shape inside to prevent the oil jolting out of the hole.

FIG. 26.

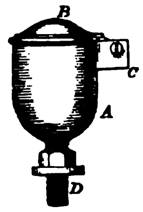
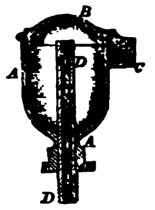


FIG. 27.



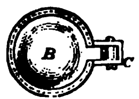


FIG. 28.

The faces of the slide valves and the outside piston rings are subject to considerable wear, from the pressure upon them and the rapidity of their motion; but the wear is very much increased when the boiler is supplied with dirty water, priming much in consequence; as the water which gets over into the cylinder carries particles of sand with it, which grind the rubbing faces very quickly. The slides in the engine shewn in the engravings have just been removed, having lasted two years; the old ones were worn down to less than a quarter of an inch thickness of flanch. The piston rings are not yet worn out; they usually last about three years. In another engine that had run upon a part of the works where the water was very bad and sandy, the piston rings were worn down to one eighth of an inch thick in four months. The cylinders get worn uneven in time by the friction of the pistons, and require reboring; about one eighth of an inch is taken off by the boring, and they are bored out generally two or three times before they are worn out; they wear usually for four years, before requiring to be rebored, but the time varies much with the quality of the metal, it being necessary sometimes much sooner.

A larger passage for the entrance of the steam is required in a locomotive than in a stationary engine, in proportion to the size of the cylinders; as the piston moves quicker, and the steam has to be admitted proportionally quicker. The best velocity for the piston of a steam engine is given by Watt as 220 feet per minute; and the area of the steam port, so as to admit the steam to move the piston at that velocity with its full pressure, he gave as one twenty-fifth of the area of the cylinder. In this locomotive, the velocity of the piston when the engine is running at 20 miles an hour is 350 feet per minute nearly, and at 40 miles an hour, nearly 700 feet per minute; the usual velocity being about 440, or double of the velocity in stationary engines. The size of the ports is one fourteenth of the cylinder, or rather less than Watt's proportion, which would be one twelfth and a half, as the piston moves twice as fast; the steam ports in some locomotives are made as large as one eleventh, and in others only one seventeenth of the cylinder, but one fourteenth appears to be a very good proportion.

The slide begins to open the steam port a little before the commencement of the stroke of the piston, so that the steam is shut off from the piston and let on to the opposite side for the commencement of the next stroke, a little before the end of each stroke; acting for this interval in opposition to the motion of the piston. This is called the lead of the slide, and it is made generally about a quarter of an inch, being produced by fixing the eccentrics a little in advance of the position at right angles to the cranks. It is found necessary to let the steam on to the opposite side of the piston before the end of the stroke, in order to bring it up gradually to a stop, and diminish the violent jerk that is caused by its motion being changed so very rapidly as five times in a second. The steam, let into the end of the cylinder before the piston arrives at it, acts as a spring cushion to assist in changing its motion, and if it were not applied, the piston could not be kept tight upon the piston rod. A little lead of the slide is also necessary that the steam may be admitted through the port into the cylinder, and be completely ready to begin the next stroke when the piston is at the end of the cylinder; but so much is not necessary for this.

The principal advantage gained by giving lead to the slide is in beginning to get rid of the waste steam before the commencement of the stroke; so that when the piston commences its stroke there is but little waste steam before it to resist its progress, the steam beginning to be let out of the cylinder before it has driven the piston to the end of the stroke. This is a very important point in a locomotive, as the resistance or negative pressure of the waste steam upon the piston is very considerable; from steam let into the end of the cylinder before the piston arrives at it acts as a spring cushion to assist in changing its motion, and if it were not applied, the piston could not be kept tight upon the piston-rod. A little lead of the slide is also necessary, that the steam may be admitted through the port into the cylinder, and be completely ready to begin the next stroke when the piston is at the end of the cylinder; but so much is not necessary for this.

The principal advantage gained by giving lead to the slide is in beginning to get rid of the waste steam before the commencement of the stroke; so that when the piston commences its stroke, there is but little waste steam before it to resist its progress, the steam beginning to be let out of the cylinder before it has driven the piston to the end of the stroke. This is a very important point in a locomotive, as the resistance or negative pressure of the waste steam upon the piston is very considerable, from the rapidity of the motion, which allows very little time for it to escape, and from the use of the blast-pipe, which obstructs its passage. The area of the extremity of the blast-pipe is only 5 square inches, while that of the steam-port is 8 square inches, requiring the velocity of the steam in the blast-pipe to be considerably greater than in the cylinder. The average negative pressure of the waste steam throughout the stroke is 6 ℔s. per square inch when running at the usual rate of 25 to 28 miles an hour; and at greater velocities the negative pressure has been found to increase to double that amount and even more. The effective pressure of the steam upon the piston at such high velocities is considerably below the full pressure of the steam in the boiler; as the steam cannot be supplied to follow up the piston so quickly with the full pressure, and the regulator has to be only partially opened, so as to throttle the steam and check its passage into the cylinders; which diminishes its pressure, as it has still to occupy the same space. The negative pressure of the waste steam amounts, for this reason, to 30 or 40 per cent. of the positive pressure of the steam upon the piston when the engine is running very fast, and the power of the engine is diminished nearly one-half.

For this reason an advantage is obtained by letting out the steam before the end of the stroke; and the steam still exerts a very considerable pressure on the piston to the end of the stroke, so that the whole power during the stroke is very little diminished though the steam begins to be let out before the end, and the resistance of this pressure of the waste steam during the next stroke is saved: the lead given to the letting out the steam, or the eduction lead, is often made greater than the steam lead, to increase this effect. The steam is shut off a little before the end of the stroke in consequence of the lead of the slide, and acts expansively for that portion, saving so much of the steam, but diminishing the total power a little: the extent of this action is, however, very limited, as the piston is less than a quarter of an inch from the end of its stroke when the steam is shut off. In stationary and marine condensing engines the steam has usually very little or no lead; but it is shut off at two-thirds or three-quarters of the stroke, giving a great amount of expansive action; and the eduction has a great deal of lead, the port being nearly full open at the commencement of each stroke.

**Feed-Pumps.**—The feed-pumps, K K (Plates I. II. and III.), are fixed by means of flanches to plates which are bolted on to the frame of the engine; they are fixed on the outside of, and a little below, the piston-rods, and exactly parallel to them. Each pump is worked by an arm, G G, fixed on to the piston-rod; it has a socket at the end, fitted on the piston-rod, and fixed by a small pointed screw tapped into it and bearing against the piston-rod: the arm is inclined obliquely downwards, so as to clear the guides of the piston-rod as it is moved backwards and forwards by the piston-rod, and attached at the outer end to the plunger of the pump. One of the pumps is shown in section in fig. 29, to three times the scale of the engraving, or 2¼ inches to a foot.

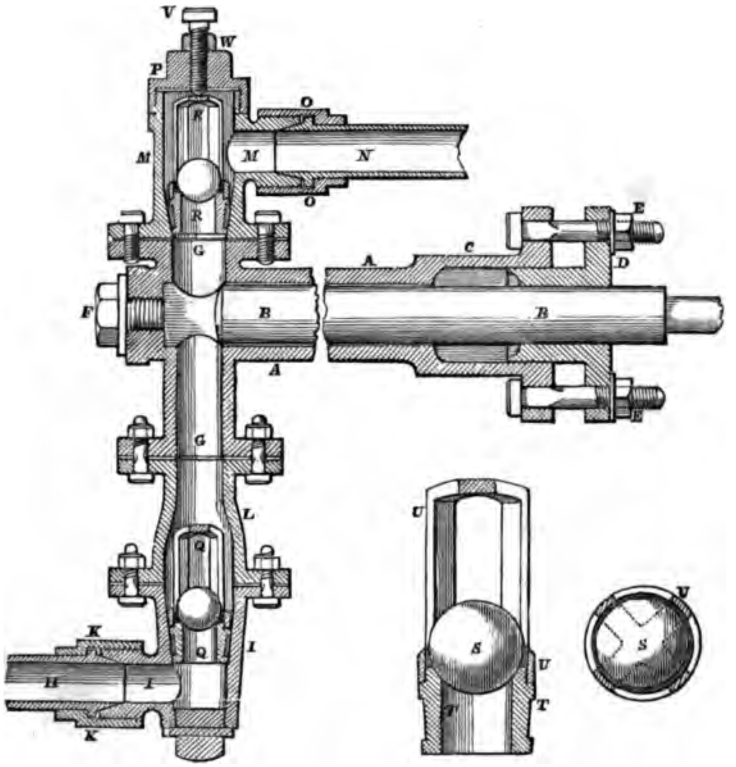


Fig. 29.

Fig. 30. Fig. 31.

The barrel of the pump, A A, is made of cast iron, 1¾ inch in diameter inside, and three-eighths of an inch thick. B B is the plunger, 1⅝ inch in diameter, and made of a wrought-iron tube for the sake of lightness, plugged up at the inner end, and having a short rod keyed into the other end, which is fixed into the socket in the driving arm by a nut screwed on the end. The plunger B passes through a stuffing-box, C, at the end of the pump barrel A, with a brass gland, D, attached by screws, E E, to the flanch of the stuffing-box. The plunger is turned truly cylindrical, to move water-tight through the stuffing-box, but the inside of the barrel of the pump is not bored, as the plunger does not touch it.

A plug, F, is screwed into the other end of the pump, to afford a passage quite through for the convenience of fixing. Two short pipes, G G, are cast upon the end of the barrel A, to the lower one of which is bolted the tube L, having the piece I fixed below it; both are of brass, and the piece I has a short tube cast on its side, with a screw made upon its outer end. H is the copper suction-pipe, having a brass collar soldered upon it with a thin conical end, which is fitted into the tube I, and held water-tight by the socket K, screwed on to the tube and bearing against the collar of the suction-pipe.

The piece M, which is bolted upon the upper pipe G, is closed at the top by a cap, P, screwed upon it, and has a tube cast on it like the bottom piece, I, into which the end of the delivery-pipe, N, is fixed by the screwed socket, O, exactly similar to the suction-pipe, H. The delivery-pipe is bent round backwards, as shown in Plate I., extending to the fire-box, where it is fixed into a valve-box, in the same manner as the other end is fixed: the pipe has to be bent in this way, that the ends may be turned in the same direction, to allow them both to be screwed into the sockets, instead of having the screws at the two ends pulling against each other. This box contains another valve like those in the pump, and is fixed on to the fire-box, communicating with the inside. The suction-pipes, K′ K′ (Plates I. II. III. and IV.), pass under the fire-box, and are connected at the end to the pipes that bring the water from the tender, being suspended by stays, *s′ s′*, from the fire-box.

In the pieces L and M are fixed the valves Q and R, which are shown to double the scale in figs. 30 and 31, where T is the valve-seat, made conical and with a groove outside, to hold packing for fitting it water-tight when driven into its place in the pump. The valve, S, is a ball, turned and ground truly spherical, fitting water-tight into its seat in every position; it is guided by the piece U U, screwed upon the valve-seat, and cut into four bars, to allow passage for the water. A pin, V, is screwed through the cap P, bearing upon the guide of the valve R, and fixed by a set nut, W, to hold down the valve-seat and prevent its being raised out of its place by the force of the pump: the lower valve-seat does not require holding, as the pressure is above it.

The plunger B, fig. 29, is worked in and out of the barrel of the pump A, a distance of 18 inches, by the piston-rod, at each stroke, leaving a space behind it when drawn out equal to its bulk, which is supplied with water through the suction-pipe and lower valve, and the water again forced out through the upper valve and delivery-pipe into the boiler when the plunger is pushed in. The internal diameter of the suction and delivery pipes, and of the water-way in the valve-seats, is 1 inch. The pump would force a quantity of water into the boiler at each stroke, equal to the bulk of the plunger, for 18 inches in length, if the suction-pipes were kept open; but the quantity is regulated according to circumstances by means of the cocks *t′ t′*, fixed in the suction-pipes, the handles of which extend upwards through the foot-board on which the engine-man stands, so as to be within his reach; and the closing these cocks causes the plunger to leave a partial vacuum behind it; and as the water cannot enter to fill it up, so much less water is forced into the boiler. In small force-pumps a plunger is preferable to a piston, because the barrel does not require boring out, as would be the case if a piston were used; and the packing of the stuffing-box upon the plunger is much more easily kept in order than the packing of a piston.

The additional valve in the delivery-pipe acts in a similar manner to the upper valve of the pump, and it is used as a security in case the other valve should get out of order from any dirt getting on its seat and preventing its closing. The valves first used for the feed-pumps were mitre-valves similar to the safety-valves; but ball-valves are now used instead, and are found to be much superior, as they are more free and certain in their action, from requiring no spindle to guide them, and keep in better order. The plungers of the feed-pumps are sometimes attached to the cross-heads, which are prolonged outside of the guide-blocks for the purpose, instead of being worked by an arm fixed on the piston-rod; but in both plans a considerable strain is caused, as the pumps are so much on one side of the piston-rod. To prevent this strain, they have been worked by eccentrics fixed upon the axle in some large engines; in which plan additional friction is produced by the eccentric, but the friction caused by the strain is quite avoided, and perhaps more than compensates for it.

## THE WHEELS, FRAMING, &c., OF THE ENGINE.

WHEELS.—The wheels are of two kinds; the two driving wheels, D′ D′, which are fixed on the crank-axle C′, are 5 feet diameter and are flat on the edge; the other four wheels, L′ M′, two of them, L′, placed towards the front, just behind the smoke-box, and the other two, M′, at the back behind the fire-box, are 3 feet 6 inches diameter, and have a projecting rim or flanch upon their edges which runs against the inner side of the rails. Each pair of the small wheels is fixed upon an axle, L″ M″, as well as the large wheels; they are 3⅝ inches diameter, and the outer ends project beyond the wheels, turning in brasses in the frame of the engine. Upon these brasses the whole weight of the engine rests through the medium of the springs above them; and all the weight is thus suspended by springs except that of the wheels and axles themselves, for the purpose of deadening the shocks that are caused by the rapid motion of the engine. It is necessary for all wheels of railway carriages to be fixed upon the axles, and have the axles turn with them, instead of turning loose upon the axles, as in carriages upon common roads, in order that they may be held quite steady and upright; for if they were to get nearer together, they would run off the rails, though in common carriages it would be of no consequence, as they would still have as firm a bearing. Also, when the wheels are fixed upon the axle, there is the leverage of the whole length of the axle to keep them upright; but when they are loose, there is only the hold of the thickness of the nave.

The construction of the wheels is shown in figs. 32, 33, 34, and 35, to a scale of an inch and a half to a foot, or double the size of the engravings. Fig. 32 is a section through the centre of one of the small wheels, and fig. 33 is a cross section through the axle and nave; figs. 34 and 35 being similar sections of one of the driving wheels. A A is the axle of each wheel; the large one is 5½ inches diameter inside the wheel, and the small one is enlarged to 4 inches; the outside bearing, B, of both, are of the same size. C C are the naves of the wheels, made of cast iron; the large one is 18 inches diameter, and the small one 13 inches; the length of both in the centre, where they are fixed to the axle, is 7½ inches, and they are fixed by four keys, E E, each, driven into grooves cut in the axles and inside the naves. The wheels are entirely supported and held by these keys, as the naves do not touch the axle; and by this means a firm and uniform bearing can be obtained, and the wheels can also be fixed truly at right angles to the axle and at the proper distance from each other. Hollows, E E, are cast in the naves between each of the keys, to diminish the metal.

The rims of the wheels, F F, are of cast iron, 4½ inches wide and 2½ inches deep; they are cast with a groove round them on the outer side, to diminish the weight; bosses, G G, are cast on the inner side, where the spokes are inserted. The spokes, H H, are wrought-iron tubes one-quarter of an inch thick, and tapering from 2¼ inches to 2 inches in diameter, and they are cast in the nave and rim. The spokes are inclined to the plane of the wheel, so as to come nearly to one face of the nave and the opposite face of the rim; and they are inclined alternately in opposite directions, as shown in the figure, for the purpose of increasing the lateral strength of the wheels, and preventing their bending and getting out of the vertical position with the great strains to which they are subjected. The spokes are laid in the moulds in which the wheels are cast, and the metal cast round them, the ends of the spokes being first

Fig. 32.

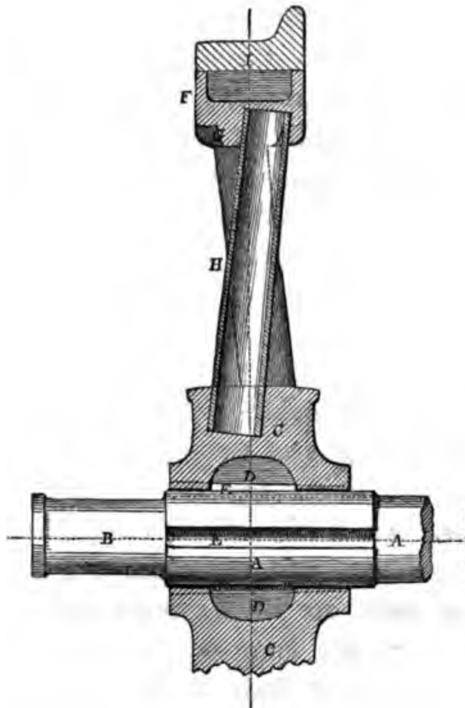
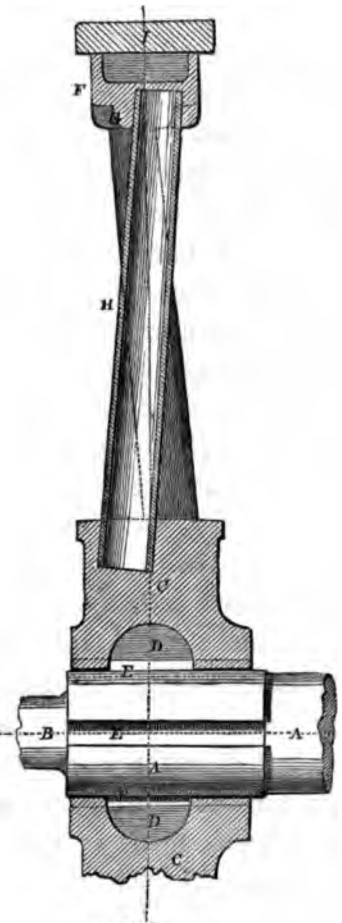


Fig. 34.



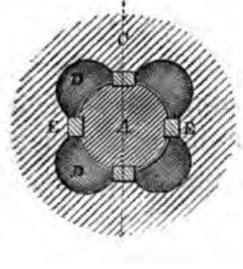


Fig. 33.

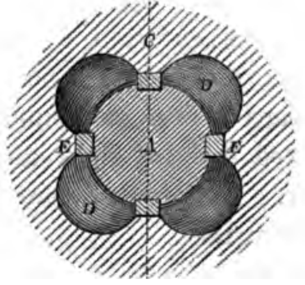
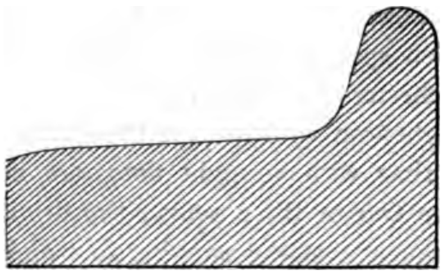


Fig. 35.

plugged up; and the spokes are covered at the ends with a composition of borax, which causes them to partially melt when the metal is poured in, forming so close and firm a joint that they never get loose. The rims of the wheels are cast first, and allowed to remain for about three-quarters of an hour before the naves are cast, because they contract much more in cooling than the naves, being of a much larger diameter, tending to force the spokes nearer to the centre; and if the naves were cast at the same time, the spokes would be prevented from approaching the centre, and there would consequently be a very great strain upon them, and the metal in the rims would not set firm from cooling in a state of tension, and would be liable to break with any blow; but by allowing the rims to set before the naves are cast, this action is prevented.

I I are the tires of the wheels; they are made of wrought iron rolled into the required shape, with the ends welded together; the plain one for the driving wheels is 5¾ inches wide, and the flanch-tire for the small wheels 4½ inches wide. Sections of the two tires are given in figs. 36 and 37, half of the real size; they are both made slightly conical, being tapered from 1⅜ inch to 1½ inch thick; and the flanch projects one inch and a quarter, and is three-quarters of an inch thick at the edge, and an inch thick at the base. The rims and tires are both turned, and the tires are heated when put on, and contract on cooling, so as to hold firmly on the wheel: great care is required in fitting them, that they may not be loose upon the wheels, nor shrunk too tight, so as to injure their texture. They are held in their places by three bolts with countersunk heads in the tires, and nuts screwed on against the inner side of the rims. The tires are turned when fixed on the wheels, to make them truly circular, and to make the two in each pair exactly alike.

Fig. 36.



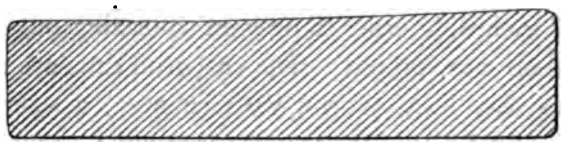


Fig. 37.

The flanch-wheels, like the wheels of all railway carriages, require to be made a little conical, in order to prevent the flanches being continually in contact with the rails, and rubbing against them, which would cause a great deal of friction; as a wheel, when running towards one side and bringing the flanch in contact with the rail, will bear upon a larger circumference than the other wheel, and will tend to run towards the opposite side, and make the wheels central again: the flanches are thus hardly required on a straight line, and only necessary upon sharp curves, to keep the wheels from running off the line. The rails are laid inclined a little, so as to fit the conical wheels; and for this reason the driving wheels have to be made also conical, although they have no flanch. The driving wheels are made without flanches, that they may always have firm hold on the rails, as a flanch on the inner one, when the engine is turning round a curve, would be forced against the inner rail, and would interfere with the bearing of the wheel, and cause friction; and flanches upon the front and hind wheels are sufficient to keep the engine upon the rails. For the improvement of making the middle driving wheels without flanches, Mr. Stephenson has a patent.

The wheels of the first engines were made entirely of cast iron, but it was found difficult to make them sound, in consequence of the unequal contraction in cooling, and they were too brittle to bear the shocks produced in running fast; the cast iron was also found to be too soft, and to wear in a groove on the edge with running on the rail; and the driving wheels could not be case-hardened, as the others were, from its diminishing the adhesion upon the rails. Wheels with wooden spokes and rims and wrought-iron tires were tried on the Liverpool and Manchester Railway, and found to wear better, being more elastic; and flat wrought-iron spokes were then tried. The wheels with tubular spokes, and cast-iron rims with wrought tires, are now very generally used, and wear very well, lasting two or three years; the driving wheels being subject to the most wear, in consequence of the slipping to which they are liable. The tires squeeze out at the sides as they wear, and when worn out are replaced by new ones; they are now made wider, the flanch-tires being 6 inches, and those of the driving wheels 7 inches, in order to prevent squeezing out at the sides, which is the greatest cause of their wearing out. The cast-iron rims are rather objectionable from their brittleness, as they have to run with so great a velocity; and to obviate this, some engines have wheels with wrought-iron rims, to which the spokes are fixed by rivets, having the tires shrunk upon them: this construction is considerably more expensive, though very durable.

All the earlier locomotives on the Liverpool Railway, and many of the present ones, have been made with only four wheels, D′ L′; the third pair of wheels, M′, placed behind the fire-box, has been added but lately; but six-wheeled engines are now coming into more general use, and on several railways none others are used. In the earlier engines the fire-box was considerably smaller than the present size, and that end of the engine behind the crank-axle was but little heavier than the other end before the front axle, so that the engine was nearly balanced upon the axles, and ran steadily along. But the weight of the hind end of the engine has been so much increased, by increasing the fire-box, that it has a considerable preponderance, and the present engines are far from balanced: in the engine shown in the engravings, the weights at the wheels D′ L′, supposing the hind wheels M′ removed, are six tons at the large wheels, D′, and only four tons at the front wheels, L′, including the weights of the wheels. This excess of weight behind the wheels causes, in the four-wheeled engines, a pitching motion, which makes them rise on the springs of the front axle, and is considered dangerous when running very fast. The pitching of the engine causes also great injury to the rails, as the wheels are made continually to strike upon them with very great force.

The hind wheels in the six-wheeled engines support the fire-box, and prevent this action: the springs over their axle are hung very light, so that in the ordinary state of the engine they only just bear against the frame, and take scarcely any weight away from the driving wheels; but they serve to catch the weight in the oscillations of the engine, and prevent that overbalancing which causes the pitching motion. The weight on the rails at these wheels is, therefore, only that of the wheels and axle, or about a ton and a quarter, when the engine is empty; and, when filled for working, the weight is about two tons, making the total weight of the engine twelve tons when full. The weight of the engine when empty is ten tons; and that of the driving wheels and axle is about a ton and three-quarters, of which the cranked axle has nearly a quarter of a ton.

When an engine is required for heavy work, as for carrying goods, and the adhesion of four wheels must be made use of for propelling it, the front wheels, L′, are made of the same size as the driving wheels, and coupled with them. The cylinders have then to be placed lower, and inclined upwards towards the cranked axle, in order that the piston-rods and guides may clear the front axle, L″, as that is raised up to a level with the cranked axle C′ and the former position of the piston-rod, by the wheels D′ and L′ being of equal size. The driving wheels are in this case sometimes made less than 5 feet, in order to increase the power of the engine, as the diminishing of the diameter of the wheels diminishes the leverage of the load upon the engine, or increases the leverage of the engine in moving the load. But the speed of the engine is diminished in the same proportion, as the smaller wheels will advance a less distance than the larger ones in the same number of revolutions; but this is not material in the carrying of heavy goods, as so great a speed is not required for them. In order to enable the engines to run faster without having to make more strokes in the same time, the size of the wheels has been increased, and a great many are now made with 6-feet driving wheels: the size of the cylinders has also to be increased to supply the increased power that is required, and they are made 13 inches diameter, with the same stroke, 18 inches. Wheels have been tried lately of double the size, or 10 feet diameter, and even larger in some instances, for the purpose of still more reducing the velocity of the piston, and diminishing the loss of power from the resistance of the waste steam, which is the great difficulty in locomotive engines. But it appears very questionable, whether the disadvantages arising from the use of such large wheels do not more than compensate for their advantages in diminishing the velocity of the piston; as there is a serious objection to them in their great weight, which, together with that of the cranked axle, also proportionally increased, is necessarily unsupported by the springs, and therefore the violent shocks produced by the rapid motion cannot be eased by them. A certain velocity of the piston is also required for the effective operation of the blast, and the velocity should for this reason be, probably, not less than 300 feet per minute. Cog-wheels, worked by the connecting-rods, have also been tried, doubling or trebling the velocity of the driving wheels; but they are objectionable, from their jarring action with so rapid a motion.

Outside Framing, &c.—The principal or outside frame, N′ O′ P′ (Plates I. II. III. and IV.), is placed along the sides of the engine outside the wheels, and across the ends, serving to support the whole engine, which is firmly fixed to it. It is made of good tough ash plank; the side pieces, N′ N′, are 3 inches thick and 7 inches deep, and covered on both sides with sound wrought-iron plates, a quarter of an inch thick, fixed on by a number of iron bolts: the best plates are termed Low Moor plates. The side pieces are mortised into the end pieces, O′ P′, of the frame; that in front of the engine, O′, being 5 inches thick, and 13 inches deep: angle pieces of iron are bolted on, to strengthen the corners inside and out. The outside length of the frame is 17 feet, and the width 6 feet 4 inches. The boiler, fire-box, and smoke-box are fixed to the side frames, N′ N′, by strong wrought-iron stays, *u′ v′*, 4½ inches wide, and half an inch thick. The stays, *u′ u′*, for the smoke-box and fire-box, consist of a horizontal piece (see Plate IV.) bent downwards at right angles at the inner end, and riveted to the side plate of the fire-box or smoke-box, and resting at the other end upon the side frame; the other inclined piece is welded on to it at the outer end, the two being bolted down to the frame, and it is riveted, like the other piece at the upper end, to the plate: the inner ends of both that are riveted to the fire-box and smoke-box are made T-shaped, and 12 inches wide. The stays, *v′ v′*, for the boiler are made and fixed in a similar manner; they are longer, as shown by the dotted lines in fig. 4 (Plate IV.), in order to reach the boiler, and have a ring of the same sized iron inserted in them, touching the horizontal and inclined pieces of the stays and the sides of the boiler, and riveted to each of them.

Q′ Q′ Q′ are wrought-iron plates, seven-sixteenths of an inch thick, bolted on to each side of the frame at the axles, and called the axle-guides, serving to hold steadily the boxes that contain the brasses bearing on the axles, and to guide them when they slide up and down from the play of the springs. A piece 4½ inches wide is cut out in the middle of each for the axle-box to slide in. These axle-guides have to resist all the strain of the wheels, and those of the driving wheels have to bear the whole force of the engine, which is moved along by the axle of the wheels. They are therefore strengthened by 1¼-inch rods, $w' w'$, fixed between each of them, with sockets across their ends, fitting between the two axle guide-plates, and fixed to them by bolts passed through both: the extreme rods are fixed to the end frames of the engine, as in Plates I. and II.; the axle-guides for the small wheels have also bolts fixed through the bottom.

R′ R′ R′ are the axle-boxes in which the axles turn; they are all alike, and are shown to three times the scale, or 2¼ inches to a foot, in figs. 38, 39, and 40. Fig. 38 is a section along the centre of one of them; fig. 39 is a cross-section; and fig. 40 a plan of the top. A A is a cast-iron box, open at the bottom and the inner side, and 4½ inches wide, so as to fit into the opening in the axle-guides. A hollow, B B, is cast in the top of the box A A, for the purpose of holding oil to supply the bearing, and in it is cast the socket C, in which the end of the spindle attached to the spring rests. The inside of the box is octagonal at the top, as shown in fig. 39, and has the brass piece D D fitted into it; which is turned out in the inside, to fit the end of the axle, reaching down to the centre, and having a small projection, E, on each side, which fits into a corresponding notch in the sides of the box A A, and serves to hold the brass steadily. Two thin brass tubes, F F, are screwed into the brass, and pass through holes in the top of the box A, projecting up into the hollow B, containing oil; and cotton thread is put into them, dipping into the oil and touching the axle at the other end, acting like a syphon in furnishing a constant supply of oil to the axle, as in the oil-cups before described.

Fig. 38.

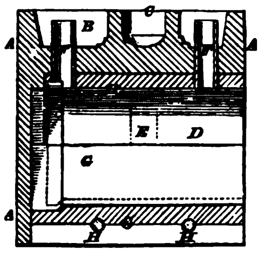
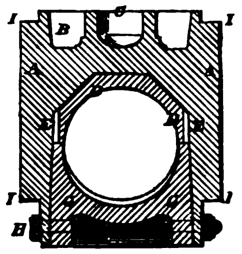


Fig. 39.



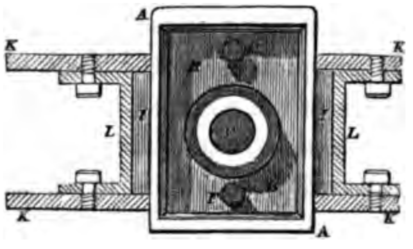


Fig. 40.

The bottom is closed by the cast-iron piece G G, made tapering to fit closely to the sides of the axle-box, and held in by the bolts H, and hollowed in the inside so as to clear the axle, the position of which is shown by the dotted lines. A piece, I I, is cast on each side of the box, projecting half an inch, which fits exactly between the two axle guide-plates, and slides between them, as shown in the plan, fig. 40, where K K is a horizontal section of the axle-guides; L L are pieces of iron plate bent so as to fit accurately between the plates K K, and bolted to them, as shown in Plate IV.; the faces of the pieces I I bear against them, and they are both made true and smooth, so as to allow the axle-box to slide up and down easily and without shaking. The top of the box is covered by a piece of sheet-iron, with a hole in it for the spindle of the spring, in order to protect the oil.

S′ S′ S′ are the springs, made as usual of separate steel plates: those for the driving wheels D′ are the strongest, consisting of thirteen plates, 4 inches wide, and five-sixteenths of an inch thick; the other springs are 3 inches wide, the front ones having twelve plates and the hind ones eight. The four small springs are placed under the outside frame, and their ends rest in sockets, $x' x'$, fixed to the frame, and are kept in by bolts put through the sockets. The larger springs are turned over at the ends, and take hold of short bolts, having the links $y' y'$ fixed on them; the lower ends of which are fixed to cross-heads on bolts, which are put down through holes in the side frame and fixed by nuts underneath. A square iron socket is fitted on to the centre of each spring, and has a steel pin, $z'$, 1⅛ inch in diameter, fixed into its under side, the lower end of which rests in the socket on the top of the axle-boxes, (C, figs. 38, 39, and 40,) and thus the frame N′ N′, which bears the whole weight of the engine, is supported by the ends of the springs, which rest at their centres upon the axles of the wheels. The bearing pins $z'$ of the middle springs pass through holes in the side frame, which serve to steady them when playing up and down; other pins are fixed in the upper side of the sockets on the other springs, which pass through holes in the frame above for the same purpose.

At the ends of the part of the frame O′, in front of the engine, are fixed the buffers T′ T′; they are strong leather cushions stuffed with horse-hair, and are placed there for the purpose of deadening the shock of any collision with another carriage. Buffers are fixed upon each end of carriages of every description that run upon a railway, being all fixed at the same height and distance apart, in order that they may be the only parts of the carriages that ever touch each other: those on the engines are sometimes made with a large spiral spring inside, that their action may be more perfect. In the centre of the end frame O′ is fixed a strong chain and hook, $a''$, for attaching the train of carriages when the engine is running backwards; a small iron plate being placed on each side of the frame for the bolt that holds the chain to be fixed against. A strong staple is also fixed into the frame on each side of the chain, as an additional means for attaching the train. The foot-board U′, upon which the engine-man stands, rests upon cross pieces of wood that are fixed to the piece of the outside frame P′, at the back of the engine, and supported at the other end by the plate *b″*; a hand-rail is fixed on each side of the foot-board as a guard, and to one of these the guides for the hand-lever *w″* are attached. *b″ b″* are two pieces of iron plate placed across the back of the fire-box, and bent at right angles along one side, forming a flanch which is riveted to the back plate of the fire-box; they are also fixed at the ends to plates which are riveted on to the sides of the fire-box. Through the centre of the plates *b″ b″* is put the draw-pin V, 1½ inch diameter, resting by its head on the top plate, and held by a key put through it under the bottom one; a socket is fitted on to it, having a pin projecting from it on each side, on which is fixed one of the links, W′ W′, which are attached in a similar manner at the other end to another socket, connected to iron bars fixed on the tender by a pin, X′, passed through them all: this pin is held by a key underneath, and is taken out when the tender is required to be disconnected from the engine. The socket on the draw-pin V′ is supported by a small ring fixed by a set nut, and the link W′ can by this means be readily adjusted level, so as to pull without side strain when the height is altered from the use of another tender, or other cause. The draw-links W′ W′ are left free to move in any direction, in order to allow for the play of the springs of the engine and tender, and the oblique direction of the pulling round a curve: when they are disconnected from the tender, they can also drop down upon the edge of the plate *b″*. The draw-pin V′ is required to be strong, to resist the great strain to which it is subjected; it is most strained when running down a considerable inclination, as the engine is not then constantly pulling, but the train often pushes against it, and a continued succession of violent jerks on the pin are produced in opposite directions: instances have occurred of the draw-pin breaking under these circumstances in engines where it was not made strong enough for its length.

Splashers, *d″ d″*, are fixed over each of the wheels, to catch the dirt thrown up by them: those for the middle wheels are of brass, and are ornamented, the others of sheet-iron, and they are fixed by small stays on to the boiler and the outside frame.

INSIDE FRAMES.—Four wrought-iron frames, Y′ Y′ (Plates II. and III.), are fixed between the smoke-box and fire-box, to afford additional strength to the engine by securing firmly the back plate of the smoke-box, in which the cylinders are fixed, and which has to bear the whole strain of the working of the engine.

These inside frames have also bearings in them for the cranked axle, and hold it steadily against the action of the connecting-rods, by which it is strained alternately in opposite directions. The frames Y′ Y′ are 3½ inches deep, and three-quarters of an inch thick; they are attached to the smoke-box and fire-box by means of T-shaped pieces of iron, which are riveted on to their inner and side plates, and are bolted to the ends of the frames: the two middle frames are made to approach each other, and are welded together at the back end, so that there are only three bearings on the cranked axle. On to the four frames are fixed the piston-rod guides, A′ A′, by means of pieces of angle iron, as before explained. The frames have to be inclined upwards towards the fire-box, in order to pass above the cranked axle.

Fig. 41.

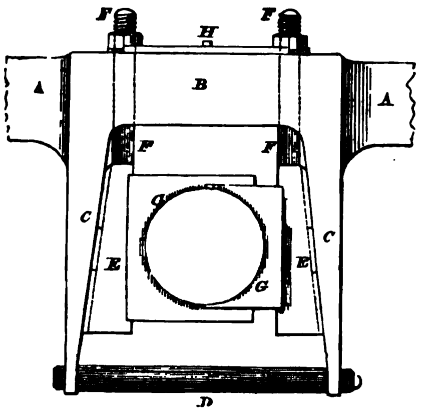
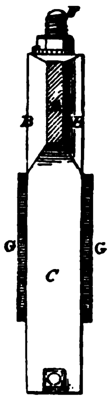
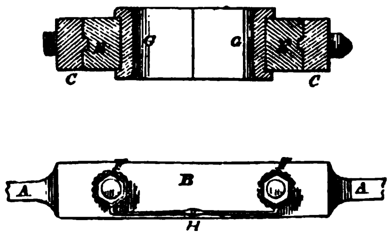


Fig. 42.





Figs. 43 and 44.

The construction of the inside bearings of the cranked axle is shown in figs. 41, 42, 43, and 44, to double the scale, or 1½ inch to the foot. Figs. 41 and 42 are side and end elevations; fig. 43 is a horizontal section through the centre of the bearing; and fig. 44 a plan of the top. The frame A A is increased at the bearing to 2¼ inches thick; the upper part B is 11½ inches wide, and the lower part is formed into a fork, C C, 10 inches long, the sides tapering 1¼ inch in width. A tube D D is fitted between them, having a bolt passed through it, by means of which the two sides of the fork are held firmly together. Two iron wedges E E are fitted accurately to the sides, so that their inner faces are parallel to each other, and will remain parallel when moved up and down. Each side C C has a small projection on its inner side, fitting into a corresponding groove in each wedge, as shown in fig. 41, to guide it when moved; and a bolt F is carried upwards from each of the wedges, E, through the upper piece B, having a nut screwed upon it at the top: the holes for the bolts are made oblong, to allow for the lateral motion of the wedges when they are screwed up. The two brass bearings G G are inserted between the wedges, having flanches on each side fitted on the faces of the wedges; they are 3 inches wide, and bored out to 5 inches diameter, to fit the cranked axle. One of the brasses G overlaps the other, which is fitted steadily into it, but not quite touching at the ends. They are made to close upon the axle by screwing up the two wedges E E, thereby forcing the two brasses nearer together; and they are then free to slide up and down between the wedges to allow for the play of the springs, which affects the engine only, and not the axle, and are readily tightened up, as they wear from friction, by screwing up the wedges further.

The cranked axle is thus steadied against the horizontal force of the connecting-rods, which is the greatest strain that it is subjected to; but it can have no vertical support, in consequence of the play of the springs. A shoulder is made on the bottom of the nuts on the bolts F, and cut into teeth, as shown in the plan, fig. 44, which catch the ends of a small spring H, fixed by a screw in the middle. This prevents the nuts from turning round and getting loose with the great jolting to which they are subject, the spring having to be forced out from each tooth in succession to let the nut turn; and though this does not impede the screwing up of the nuts, it is sufficient to prevent their getting loose. The same contrivance is applied to all the nuts in the engine that are used for the adjustment of some moveable part, as those in the glands of the piston-rod and slide-valve spindle, as these nuts are not screwed hard up so as to keep them fast.

Some engines with four wheels are made without the outside frame, and also have not the inner ones; and, instead of them, a strong iron frame is placed immediately within the wheels, bearing upon the axles, and having the whole engine resting upon it: this gives the engine a lighter appearance, as the wheels are quite on the outside. But the outside frame adds considerably to the stiffness of the engine, and is of great utility in that respect, particularly when the engine gets thrown off the line, as happens occasionally; when the outside frame serves materially to protect the machinery. It has also an advantage in enabling the engine-man to have access to any part of the engine whilst it is working, as the wheels and the space between them are covered over by the splashers, and can be readily passed over: this is very useful, as the working parts frequently require examining and replenishing with oil whilst running. The friction is less when there is no outside frame, as there are but two bearings on the cranked axle, instead of five; but they have to be the full size of the axle, as they are inside the wheels, which much increases the friction of each, and renders the whole but little less than in the other plan: the axle is also not held so steadily as with the middle inside bearings.

WHISTLE.—*Z'* (Plates I. II. and IV.) is a steam-whistle used for the purpose of giving warning of the approach of the engine when running; the construction of it is shown, to one-quarter size, or four times the scale of the engravings,

Fig. 45.

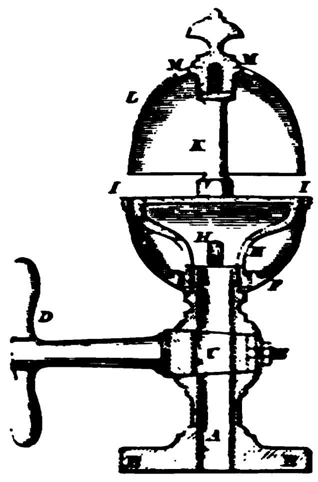
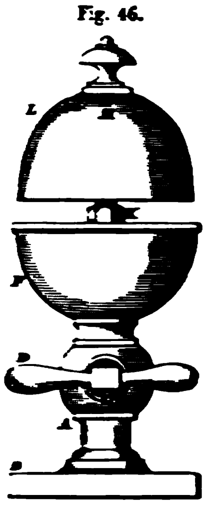


Fig. 46.



in figs. 45 and 46. It is all of brass, and the foot, A, is cast hollow, with a flanch, B, at the bottom to bolt it upon the fire-box: it has a cock, C, placed in it, with the handle D, and screw E, to keep it tight; the handle projecting out to allow firm hold to be taken of it. The cup F is fixed upon the foot A, by screwing the piece G upon it, and both are turned truly at their outer edges, leaving a very narrow passage, I I, four inches diameter, between them all round. The piece G is hollow, having holes, H, in its sides; and a pillar, K, stands upon its centre, on which is screwed the bell, L L, the thin edge of which is brought just over the opening I, and half an inch above it. When the cock is opened, the steam enters the cup F through the holes H, and rushes out at the narrow slit I, striking the thin edge of the bell, L, in a similar manner to the action in organ-pipes, and producing an exceedingly shrill sound: some holes M are made in the top of the bell, to allow the steam to pass freely through, which improves the sound considerably. The cock is required to be steadily opened, to adjust the quantity of steam, so as to produce the clearest sound. The steam-whistle is very effective, and its sound can be heard at a great distance.

## THE TENDER.

The tender is attached behind the engine and close to it: it contains a tank of water for supplying the boiler, and has a space in the middle filled with coke for feeding the fire. A side elevation of it is shown in Plate I., a longitudinal section in Plate II., and a plan in Plate IV.

FRAMING.—The side frames A′ A′ are made double, with diagonal bracing pieces inside them, and are connected by strong pieces at the ends. The floor is supported by diagonal and cross pieces, dotted in the plan, which are fixed into the sides and ends, and the joints of these pieces are strengthened by iron plates; the plate in the centre is shown at z′, extending along each of them. An iron bar, B′ B′, is fixed upon the bottom along the centre, and another bar bolted to it underneath at the front, the two projecting beyond the front, and having holes in their ends through which the pin X is passed, to connect the socket at the end of the drawing links W′ of the engine. A chain and hook, *y*″, is fixed on to the other end of the draw-bar B″, for the purpose of attaching the train of carriages: in this end of the bar a large square socket is made, and is fitted upon the middle of the long spring C″. D″ D″ are the buffers, faced with leather cushions, and fixed upon iron spindles which pass through holes in the centre of two blocks of wood, *z*″ *z*″, that are bolted upon the end of the frame; and the spindles have sockets in the outer ends, in which the ends of the spring C″ rest; and when the buffers strike against those of another carriage, they press against the spring C″, which yields and reduces the shock of the collision.

WHEELS.—The tender runs upon four wheels, G″ G″, three feet in diameter, which turn in the space between the pieces of the side frames; they are made with flanches, and are similar to the small wheels of the engine. The wheels are keyed upon the axles, which are 3½ inches diameter, and turn at their outer extremities in axle-boxes similar in principle to those of the engine; the axle-guides consist only of a single plate, each three-quarters of an inch thick, bolted on to the inside of the outer pieces of the frame, and the axle-boxes have grooves cast in their sides, into which the edges of the axle-guides are fitted. The springs H″ H″ are fixed down upon the top of the axle-boxes by two bolts, made each into a large eye at the upper end, which fits upon the spring, and the ends of the springs rest in sockets fixed upon the under side of the outer piece of the frame. The tenders for the largest engines are often placed upon six wheels, to diminish the weight upon each wheel.

TANK.—I″ I″ is the water tank, made of wrought-iron plates one-eighth of an inch thick, riveted together and joined at the corners by angle iron; it is of a horse-shoe shape, 9 feet long, 6¾ feet wide, and 2¼ feet deep. It is supported upon the side and end frames and a cross piece in the middle, and is held in its place by pieces of strong angle iron fixed on to the frame and standing up to hold the front and back ends. The top of the tank is covered with the board K″, having sides of iron plate fixed upon it; and a raised part, N″, is made at the back, divided into three portions, covered with lids on hinges; the middle one containing an opening, O″, into the tank, 12 inches square, surrounded by iron plate brought up to the top, for the purpose of supplying the tender with water. The other spaces on each side are used as tool-boxes for holding the different articles that are constantly in requisition in the engine. A copper pipe, P″, is fixed underneath each end of the tank, communicating with it, and passing through the floor, having a cock in it to close the pipe when disconnected from the engine. The hose-pipes Q″ Q″, that are attached to the suction-pipes K′ K′, for the feed-pumps of the engine, are connected with them by screwed sockets or union joints, which can be readily unfastened when the tender has to be separated from the engine. The hose-pipes are made of leather or Indian rubber cloth, with a spiral spring inside, to keep them open, like the suction-pipes of fire-engines; a flexible pipe being necessary to allow for the variations of motion between the engine and tender. There is used sometimes, instead of the flexible hose, a metal pipe with a double ball and socket and a sliding joint, to allow motion in every direction: this has the advantage of not requiring repairs so often as the hose.

COKE.—The middle space of the tender, R″ R″ R″, is occupied with coke, the front end being made level with the foot-board of the engine, and a board, S″, fixed inclining from thence down to the floor, for the convenience of taking up the coke with a shovel to throw it upon the fire: the bottom and sides are covered with sheet-iron.

The BRAKE for stopping the wheels is shown in Plate I., and consists of two wrought-iron frames hung by pins from the side frame of the tender, and having blocks of wood fixed on to them, that are cut to fit the circumference of the wheels. A flat iron wedge fits into grooves in the two frames, and is continued up by a rod to the top of the tender, passing through a strong iron piece, W″, and having the double handle X″ screwed upon it. By screwing down the handle the wedge is drawn gradually up, and the two brakes are separated from each other, pressing the wood of each very forcibly against the wheels until they are stopped, if necessary. This brake is used to stop the engine and train quickly, and others are also used on the wheels of some of the carriages in the train: the brakes are of many different constructions, but this one is very simple and convenient, and has great power. A step and a handle are fixed on to the tender on each side, for the convenience of getting upon it or upon the engine.

The tender weighs, when empty, 3½ tons, and about 7 tons when filled with water and coke. The tank holds about 700 gallons of water, and the quantity of coke that is carried is about 8 cwt.: these are sufficient to supply the engine for running from thirty to forty miles, according to the load taken; but the tender is seldom run further than twenty miles without being refilled.

The power of a locomotive engine cannot readily be estimated in the same manner as that of other engines, by taking the actual force upon the piston, and the velocity of its motion; for it is very difficult to ascertain the effective pressure of the steam upon the piston, in consequence of its differing often very considerably from that of the steam in the boiler, and because of the large amount of the resistance of the waste steam, owing to the great velocity with which the piston moves.

The power is also different at different velocities, as these circumstances vary with the velocity. The only correct means, therefore, of ascertaining the power of a locomotive, is by deducing it from the work that it is capable of performing.

This engine has drawn a load up an inclined plane that was equivalent to 220 tons gross weight upon a level, (including engine and tender,) at a velocity of 14 miles an hour; which appeared to be about the extent of the power of the engine with the steam at the usual pressure of 50 ℔s. on the square inch, in the boiler. The force required to perform this is about 2050 ℔s., moving at that velocity, which is equal to 77 horse-power. The effective pressure on the piston, or the actual force with which it was propelled, must, therefore, have been 47½ ℔s. per square inch, instead of 50 ℔s., which was the pressure of the steam in the boiler; the difference being the power that was lost by the resistance of the waste steam, and by the diminution of the pressure of the steam, in consequence of the throttling or wire-drawing that takes place in passing through the ports of the cylinders, and which was in this instance very inconsiderable.

The horse-power of an engine is less when drawing a lighter load at a greater velocity, as the loss of power from the throttling and the waste steam is then increased; and it would cease altogether at a certain speed, varying according to the proportions of the engine, when the velocity of the piston became as great as that with which the steam can enter into the cylinder, or the waste steam escape. This engine has drawn 40 tons at 35 miles an hour, which is equivalent to 40 horse-power; in which case the effective pressure on the piston must have been only 10 ℔s. on the square inch, or but one-fifth of that of the steam in the boiler. This shows the great loss of power in working the engine so quickly; the loss at 14 miles an hour having been very little. This loss of power is lessened by making the wheels larger, the velocity of the piston being by that means diminished; and they are consequently made as large as is practicable.

The power of a locomotive engine is limited only by the evaporating power of the boiler, or the number of cylinders-full of steam that can be supplied in a given time, by which the velocity of the piston is determined; while in other steam engines the size of the cylinders is the limit to the power, as a sufficient quantity of steam to supply them can be readily obtained by increasing the size or number of the boilers, which cannot be done in a locomotive. This engine is capable of evaporating 77 cubic feet of water per hour, or eight gallons in a minute; and the large amount of this power causes its great superiority to the old locomotives, which could evaporate only about 16 cubic feet per hour.

The consumption of fuel per mile for every ton of the gross load is about a quarter of a pound, and that of the water is rather less than a quarter of a gallon; the consumption increasing to nearly one-half, according as the engine is less fully loaded, being proportionally greater with a light load: the consumption of water, when working with a full load, is a cubic foot per hour for each horse-power, which is also the usual proportion in stationary engines, although they condense the steam. About 8 ℔s. of fuel is required to evaporate a cubic foot of water, being nearly the same as in stationary engines; but in the old locomotives as much as 18 ℔s. was required, in consequence of their having so small a heating surface, which was only about 2½ square feet for each foot of water evaporated per hour; the proportion in the present one being 5½ square feet, and in stationary engines as much as 8 square feet.

The great perfection of the present locomotives, and their superiority to the old ones, is caused not so much by the application of new inventions to them, as by the combination of many former ones, and the uniting together several plans which, separately, would be but of small value. Their great power and velocity, for example, could not have been obtained without the rapid means of generating steam afforded by the use of the tubes; and the tubes would have been useless without the powerful draught produced by the blast, which increases in intensity with the velocity, and with the necessity for its increased action.

## DIVISION A.—LOCOMOTIVE ENGINES.

SEVENTH PAPER.

# SPECIFICATION

FOR

# THE PASSENGER ENGINES ON THE CALEDONIAN RAILWAY.

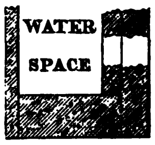
**Wheels 6 feet in diameter,—cylinders 15 inches in diameter, and stroke 20 inches.**

*Barrel of Boiler.*—To be cylindrical, 9 feet 9 inches long and 3 feet 6¾ inches in diameter outside; to be made of the best Low Moor or Bowling plates, ⅜ inch thick, well riveted together with ¾-inch rivets, 2 inches apart from centre to centre; to be fixed to the fire-box and front tube-plate with strong 3-inch angle iron, with a single row of ¾-inch rivets, 2 inches apart from centre to centre. A wrought-iron man-hole ring, 4 inches deep, to be fixed on the barrel of the boiler, in the position and of the form and dimensions shown on the drawing, with ¾-inch rivets, 2 inches apart from centre to centre: the upper surface of the ring, as also the man-hole door or cover, to be perfectly flat, and ground together so as to make a steam-tight joint with a little red lead putty: the cover to be bolted with ¾-inch bolts, 2½ inches apart from centre to centre.

Eleven wrought-iron stays to be placed longitudinally through the boiler, tapped and screwed into the outer plate of the fire-box, but not screwed into the iron tube-plate; to be secured by lock nuts, as shown on the drawing: the stays to be 1⅛ inch in diameter at the screws, and ⅞ inch between the screws. The tube-plate at the smoke-box end to be of the best Low Moor or Bowling iron, ⅝ inch thick, to be turned back as shown on the drawing, so as to require no angle iron inside: the holes in both tube-plates to be drilled parallel and exactly square with one another, very slightly rounded at the outer edges. Boiler to have two washing-out plugs, 1½ inch in diameter, to be screwed into holes in the iron tube-plate in the places indicated.

*Outside Fire-Box.*—To be made of the best Low Moor or Bowling plates, ⅜ inch thick; the rim of the fire-hole plate to be turned back with a radius of 3 inches, so as to require no angle iron: the whole to be riveted together with ¾-inch rivets, 2 inches apart from centre to centre.

An oval fire-hole in the situation and of the shape and size designated (the plate to be dished inwards, so that with a corresponding concavity of the inner fire-box plate the water space at that spot will be contracted to 1¼ inch), is to be fitted with a copper ring 1¼ inch thick and 2 inches broad, riveted with ¾ iron rivets, 2 inches apart from centre to centre, counter-sunk on the outer plate. The fire-door to be made as shown in the drawing, and, when shut, to be as nearly air-tight as possible: a chain to be fixed to the latch of the fire-door, so that it may be opened without stooping. Upon the fire-box top is to be placed a wrought-iron ring 5½ ins. deep, similar to that described for the man-hole; to be 1 foot 5 inches diameter, and surmounted by a wrought-iron dome of the same diameter: the flanges of the ring and dome to be ground together, as described for the man-hole and cover. The dimensions of the outer fire-box to be as follows: length, 3 feet 7⅜ inches; breadth, 4 feet 1⅛ inch; height, 5 feet 2¾ inches,—all outside measurements. A blow-off cock, 1½ inch diameter, to be placed in the position shown, and to be worked by a socket-rod and lever projecting an inch above the foot-plate. Round mud-holes at each corner of the fire-box, 2 inches diameter, to be tapped and furnished with screwed plugs; to be lined at the holes with pieces of plate, which will give more threads for the plug to hold by: two gauge-cocks, ¾ inch, at the right-hand side of the fire-box; the lower one 2½ inches, and the upper one 5 inches: above the inner fire-box top, a water-gauge and glass in the position shown: lamp iron to be fixed on the flange of the gauge-glass, and the socket to be          in diameter.



*Inside Fire-Box.*—To be of the best copper from Vivian & Co., Biscoe, Greenhill & Co., or other parties approved by the undersigned, entirely free from defects or flaws. Length to be 3 feet; breadth, 3 feet 6 inches; height, 3 feet 8 inches,—all inside measurements: the tube-plate to be ¾ inch thick, and the other plates $\frac{7}{16}$ inch. The whole to be well riveted together with ¾ iron rivets, 2 inches apart from centre to centre. Lead plug, ¾ inch diameter. The outer and inner fire-boxes to be stayed together with copper stays ⅞ inch in diameter, and placed as shown on the drawing; the stays to be tapped and tightly screwed into both plates, and well riveted at the ends. Eight supports to be bolted to the roof of the inside fire-box, in the position and of the form and dimensions shown; they may be made of two plates, fullared out to form the holes, and welded at the edges, or of hammered scrap,—at the option of the contractor.

*Smoke-Box.*—To be of the best Staffordshire plates, ¼ inch thick; the front to be fixed with bolts, and to have a door hung upon malleable iron hinges; the bottom also to be hung with hinges, so that it may fall and allow of working at the steam chests.

A small sliding door is required in the bottom, for letting out the ashes.

The Company to be at liberty to prove the boiler and fire-box to 120 ℔s. per square inch; and any damage thereby sustained to be made good by the contractor.

*Chimney.*—To be 15 inches diameter; plates, No. 12 wire-gauge.

*Grate-Bars.*—The grate-bar frames and grate-bars to be made of malleable iron: shape and dimensions given in drawing.

*Ash-Box.*—Good Staffordshire plate, ¼ inch thick, made as per drawing.

*Tubes.*—One hundred and fifty-eight in number, 1¾ inch in outside diameter, to be made solid, and drawn out of the best tough brass, No. 14 wire-gauge. To be placed 2½ inches apart from centre to centre, and well fastened with steel ferrules into the boiler ends; the ferrules in the smoke-box end to be ⅛ inch wider in the bore than those in the fire-box: the tubes to have a bare ⅛ inch of lap over each end of the boiler.

*Stays, or Brackets, for supporting the Boiler.*—At the smoke-box end the front plate of the smoke-box rests upon the inside frame; the middle support is of sound Low Moor plate ½ $\frac{1}{16}$ thick, riveted to the boiler and well bolted to the frame, as shown in the drawing. At the fire-box the support is of 3½-inch angle iron, firmly bolted to the frame, as shown in the drawing, but with oval holes, to allow for the expansion of the boiler when hot. The supports may either be of best Low Moor or Bowling iron.

*Outside Frame.*—Of best Low Moor or Bowling iron, securely riveted, and made exactly as shown on the drawing.

*Inside Frame.*—Of the form and dimensions shown; to be of the best-hammered scrap. All holes through the framing to be carefully rose-butted, and all the bolts to be turned and tightly driven in.

*Cross-Frame under Barrel of Boiler.*—To be of the best Low Moor or Bowling iron, securely riveted, and made exactly as shown in the drawing.

*End Plate of Framing.*—To be of Staffordshire iron, ½ inch thick.

N. B. The angle iron for securing the covering plates of the framing may be of Staffordshire iron; but all the rest, upon which the stiffness of the frame depends, must be of the best Low Moor, and carefully riveted.

*Springs.*—To be made of the best steel, exactly as shown on the full-sized drawings as to form and dimensions; the trailing springs to be elliptic, with an arrangement for relieving them at pleasure from the weight resting on them. The pins which near upon the steps to be 1¼ inch in diameter; all the springs to be severely tested before use, so that they may not set when the weight of the engine is placed permanently upon them.

*Wheels.*—Engine to have six wrought-iron wheels, made precisely of the shape and strength shown in the drawing. Tires to be of the best Low Moor iron, 4¾ inches broad, and 2 inches thick when finished: the rim of the wheels and inside of the tires to be turned before they are put together: the driving wheels to have eight conical turned bolts through the tire and rim; the leading and trailing wheels to have five: the naves to be carefully bored and fitted to the axles, four key-grooves in each nave, 1½ inch wide, ¾ inch deep, having 1/16 taper.

*Axles.*—To be made of the best scrap iron or faggoted Low Moor iron, and accurately turned and fitted in the bearings, &c. to template, to be furnished by the Company: the working bearings of all the axles to be well case-hardened.

*Cylinders.*—To be 15 inches diameter and 20 inches stroke, and cast of best metal, entirely free from honeycomb: the stuffing-box covers to be cast brass, with brass bushes and glands, and furnished with the necessary cocks, handles, oil-cups, &c., &c., as shown in the drawing; the apertures to be 10 inches long by 1¼ inch wide. Cylinder covers (cast iron) and steam chest covers (wrought iron) to be ground to their respective seats, so as to make perfect joints without canvas; the steam chest joints to be similarly made; cylinder to have a double cover of copper as per detail drawing, and to be furnished with the cylinder cocks, &c., &c.

*Slide-Valves.*—To be of gun-metal, and connected by a wrought-iron framing having spindles 1 inch diameter, passing out at each end of the smoke-box.

*Pistons.*—To be 3 inches thick, and constructed, according to the drawing, of the best tough brass; the packing rings also to be of brass. Piston-rod to be of the best tough iron, case-hardened.

*Cross-Heads.*—To be made of the best wrought iron, according to drawing. Piston-rod to pass through the socket.

*Connecting-Rods.*—To be made of the best faggoted iron, according to drawing, with a double set of split cotters, dove-tails, &c., &c.

*Valve-Gearing.*—To be made precisely as the drawing: all the pins are to be thoroughly case-hardened, and all the eyes steeled with sheer steel bushes.

*Steam-Pipes.*—In the boiler and smoke-box, to be 4½ inches in diameter, and of the best copper, No. 6 wire-gauge; all the flanges to be recessed (as shown on the full-sized drawings), except that to the smoke-box plate, which must be made with canvas and red lead: with this exception, the joints are to be made as above directed, and faced and ground so as to require nothing but a little red lead to make a perfect joint: they are to be bolted with ¾-inch bolts.

*Blast-Pipe.*—Of the best sheet copper, No. 6 wire-gauge, shaped as per drawing; all joints to be recessed and ground, and to be bolted with ¾-inch bolts. Pipe to be 5 inches diameter at the bottom, and 4½ inches at the top end; the top of the pipe to be level with the bottom of the chimney, and placed exactly in the centre.

*Regulator.*—To be made of brass, exactly as shown in the full-sized drawing.

*Feed-Pumps.*—To be of the best brass, of the exact size and form given. To be fitted with a double set of valves: all joints to be recessed and ground and screwed together with ¾-inch bolts and nuts. The pump-barrel and clack-seats must be bored truly out. The pump to be supplied by two feed-pipes, which, together with the whole arrangement of pumps, clacks, levers for working feed-cocks, &c., &c., are shown on the drawing.

*Ball and Socket Junction Pipes.*—To be made of the best tough brass, and precisely similar to the drawing.

*Safety-Valves.*—Best brass, 2½ inches diameter, provided with Salter's patent spring-balances graduated to 90 lbs.; the levers to be proportioned as shown on the drawing, namely, as 5 to 1.

*Lagging or Sheathing.*—Boiler and fire-box to be felted with ½-inch felt: wood-lagging is then to be put on in the usual way, and the whole to be covered with floor-cloth, secured by iron hoops 1¼ inch broad, having tightening screws under the boiler. Fire-box to have copper corner-plates, each secured by two bolts.

*Dome Casing.*—To be of good copper, No. 14 wire-gauge.

*Oil-Cups.*—All glands to have oil-cups cast on them; and all rods, eccentric-straps, &c., &c., to be finished with oil-cups, as shown in the drawings.

*Name Plates.*—To be of cast brass, polished.

*Number Plates.*—Also of cast brass, diamond-shaped, 12 inches by 6 inches, to be fixed on the centre of the buffer-plank.

*General Stipulations.*—Engine to be furnished with a lifting jack, a complete set of spanners, a hand hammer, and six chisels, besides all the necessary fire-irons, shovel, &c., &c., and to be made according to this specification, and to drawings to be furnished by the Company. The materials and workmanship to be of the best description for the various parts, applied in the best manner, and no advantage whatever is to be taken of any omission of details in the drawings, or in this specification, as full explanation and complete detail drawings will be given to the contractor for any part of the work not sufficiently shown or understood; but the whole is to be complete in every respect, and to the satisfaction of the undersigned, or of any other person who shall be appointed to inspect the work during its progress in the contractor's works, when he may think proper to do so. Great care must be taken that the axles are precisely the dimensions required by the drawings and templates, so that they may be exact copies of one another. All the working parts of the machinery to be well case-hardened. To insure this, they must be in the furnace at least twelve hours. The engines are to be well painted and varnished, and to be subjected to six days' trial of two trips per diem, and the contractor to be entirely responsible for any damage resulting from bad materials and workmanship; but should the engines prove to be in perfect order, the contractor will then be relieved from further responsibility.

Greenock, May 29th, 1846.

*Some of the Dimensions of the Passenger Engine* 'No. 15.'

The barrel of the boiler is 9 feet 9 inches long, 3 feet 6¾ inches in diameter; plates ⅜ of an inch thick.

The tubes, 158 in number, are of brass, 10 feet 1⅛ inch long, and 1¾ inch diameter outside.

The inside copper fire-box is 3 feet long, 3 feet 6 inches wide, and 3 feet 8 inches deep.

Cylinders are 15 inches diameter; 20 inches stroke.

Steam-ports, 10 inches by 1¼ inch; exhaust-ports, 10 inches by 3 inches.

Diameter of steam-pipe to each cylinder, 4¾ inches.

Length of connecting-rod from centre to centre, 5 feet.

Driving wheels, 6 feet diameter, of solid wrought iron.

Leading and trailing wheels, 3 feet 6 inches diameter, ditto, ditto.

Driving wheels from leading wheels, 5 feet 6 inches.

„ from trailing ditto, 6 feet 6½ inches.

From top of rail to top of barrel of boiler, 7 feet ½ inch.

From top of rail to top of chimney, 13 feet 6 inches.

Two safety-valves, each 2½ inches diameter.

Diameter of feed-pump rams, 3¾ inches; stroke, ditto, 4 inches.

Inside journals of driving axle, 5¼ inches diameter, 6½ inches long.

Outside journals of leading and trailing axles, 4 inches diameter, 6 inches long.

The tender contains 800 gallons, on four wheels of 3 feet 6 inches diameter, with wrought-iron spokes and cast-iron naves.

Distance between centres of wheels, 7 feet 11¼ inches.

The following Tables give the Duty of the Passenger Engine 'No. 15,' in making the several trips specified, between Glasgow and Carlisle, in the month of June, 1849.

*Particulars of a Trip from Glasgow to Carlisle, 22nd June,* 1849.

| STATIONS. | Miles. | Total time running. | Average speed per hour. | Average accelerating effect of a ton. | Average retarding effect of a ton. | Number of carriages. | Estimated weight of train, including engine. |
|---|---|---|---|---|---|---|---|
| | | Minutes. | Miles. | lbs. | lbs. | | Tons. |
| Southside | | | | | | | |
| | 2 | 5 | 24 | — | 10 | 7 | 63 |
| Rutherglen | | | | | | | |
| | 2 | 5 | 24 | — | 8·5 | | |
| Cambuslang | | | | | | | |
| | 3 | 7 | 26 | — | 4·8 | | |
| Uddingstone | | | | | | | |
| | 5 | 14 | 21·4 | — | 9·75 | | |
| Motherwell | | | | | | | |
| | 3 | 8 | 23 | — | 19·5 | | |
| Wishaw | | | | | | | |
| | 4 | 12 | 20 | — | 18·9 | | |
| Carluke | | | | | | | |
| | 1 | 5 | 12 | — | 21·1 | | |
| Braidwood | | | | | | | |
| | 5 | 10 | 30 | — | 4 | | |
| Lanark | | | | | | | |
| | 2·5 | 8 | 18·75 | 7·21 | — | 9 | 73 |
| Carstairs | | | | | | | |
| | 7 | 17 | 24·1 | — | 6·2 | | |
| Symington | | | | | | | |
| | 4 | 7 | 35·3 | 5·56 | — | | |
| Lamington | | | | | | | |
| | 4·5 | 13 | 23 | — | 7·46 | | |
| Abington | | | | | | | |
| | 5 | 13 | 23 | — | 8 | | |
| Elvanfoot | | | | | | | |
| | 13·5 | 25 | 33·3 | 17·2 | — | | |
| Beattock | | | | | | | |
| | 5 | 11 | 27·2 | 7 | — | | |
| Wamphray | | | | | | | |
| | 5·5 | 11 | 30 | 17·4 | — | | |
| Nethercleugh | | | | | | | |
| | 3 | 7 | 26 | — | 4 | 8 | 68 |
| Lockerbie | | | | | | | |
| | 6 | 11 | 33 | 1·93 | — | | |
| Ecclefechan | | | | | | | |
| | 3 | 8 | 23 | 2·6 | — | | |
| Kirtlebridge | | | | | | | |
| | 4 | 9 | 27·2 | 17 | — | | |
| Kirkpatrick | | | | | | | |
| | 4·5 | 9 | 30 | 11·2 | — | | |
| Gretna | | | | | | | |
| | 4·5 | 10 | 30 | — | 1 | | |
| Rockcliffe | | | | | | | |
| | 4 | 8 | 30 | — | 6 | | |
| Carlisle | | | | | | | |

Coke consumed on trip (including getting up steam), 13 cwt.
Water evaporated, 242 cubic feet.
lbs. of coke per cubic foot of water evaporated, 6·02.
Consumption of coke per mile run, 14·56 lbs.
Weather fine,—rails dry,—no wind.

*Particulars of a Trip from Carlisle to Glasgow,* 22*nd June,* 1849.

| STATIONS. | Miles. | Total time running. | Average speed per hour. | Average accelerating effect of a ton. | Average retarding effect of a ton. | Number of carriages. | Estimated weight of train, including engine. |
|---|---|---|---|---|---|---|---|
| Carlisle | | Minutes. | Miles. | lbs. | lbs. | | Tons. |
| Rockcliffe | 4 | 12 | 20 | 6 | — | 6 | 58 |
| Gretna | 4·5 | 10 | 30 | 1 | — | | |
| Kirkpatrick | 4·5 | 12 | 23 | — | 11·2 | | |
| Kirtlebridge | 4 | 8 | 30 | — | 17 | | |
| Ecclefechan | 3 | 8 | 23 | — | 2·6 | | |
| Lockerbie | 6 | 12 | 30 | — | 1·93 | | |
| Nethercleugh | 3 | 7 | 26 | 4 | — | | |
| Wamphray | 5·5 | 13 | 26 | — | 17·4 | | |
| Beattock | 5 | 13 | 23 | — | 7 | | |
| Elvanfoot | 13·5 | 33 | 24·1 | — | 17·2 | | |
| Abington | 5 | 12 | 24·1 | 8 | — | | |
| Symington | 8·5 | 20 | 26 | 5 | — | | |
| Carstairs | 7 | 14 | 30 | 6·2 | — | 4 | 48 |
| Lanark | 2·5 | 6 | 24·1 | — | 7·21 | | |
| Carluke | 6 | 11 | 33 | 4 | — | | |
| Wishaw | 4 | 9 | 27·2 | 20 | — | | |
| Motherwell | 3 | 7 | 21·4 | 19·5 | — | | |
| Uddingstone | 5 | 9 | 33 | 9·7 | — | | |
| Southside | 7 | 14 | 30 | 8 | — | | |

Coke consumed, 9 cwt. } A return trip,—steam already up.
Coal consumed, 2 cwt. }
Water evaporated, 212·3 cubic feet.
Consumption per mile run, { coke, 10·08 lbs.
{ coal, 2·24 lbs.
lbs. of fuel for each cubic foot of water evaporated, 5·8.

*Particulars of a Trip from Glasgow to Carlisle, 25th June,* 1849.

| STATIONS. | Miles. | Total time running. | Average speed per hour. | Average accelerating effect of a ton. | Average retarding effect of a ton. | Number of carriages. | Estimated weight of train, including engine. |
|---|---|---|---|---|---|---|---|
| | | Minutes. | Miles. | lbs. | lbs. | | Tons. |
| Southside . . . . . . . | | | | | | | |
| | — | — | — | — | — | 3 | 43 |
| Gushat Junction . . . . | | | | | | | |
| | — | 2 | — | — | — | 5 | 53 |
| Motherwell . . . . . . . | | | | | | | |
| | 12 | 20 | 32·7 | — | 8·26 | | |
| Carstairs . . . . . . . | | | | | | | |
| | 15·5 | 28 | 33·2 | — | 11·25 | | |
| Beattock . . . . . . . | | | | | | | |
| | 34 | 52 | 39·2 | ·23 | — | | |
| Lockerbie . . . . . . . | | | | | | | |
| | 13·5 | 20 | 40·5 | 6·8 | — | | |
| Carlisle . . . . . . . . | | | | | | | |
| | 26 | 38 | 41 | 4·28 | — | | |

Coke consumed on trip (including getting up steam), 13 cwt.
Water evaporated, 223·5 cubic feet.
Consumption per mile, coke, 14·41 lbs.
lbs. of fuel for each cubic foot of water evaporated, 6·5.

*Particulars of a Trip from Carlisle to Glasgow, 25th June,* 1849.

| STATIONS. | Miles. | Total time running. | Average speed per hour. | Average accelerating effect of a ton. | Average retarding effect of a ton. | Number of carriages. | Estimated weight of train, including engine. |
|---|---|---|---|---|---|---|---|
| | | Minutes. | Miles. | lbs. | lbs. | | Tons. |
| Carlisle . . . . . . . . | | | | | | | |
| | 26 | 45 | 34·6 | — | 4·28 | 6 | 58 |
| Lockerbie . . . . . . . | | | | | | | |
| | 13·5 | 23 | 35·2 | — | 6·8 | | |
| Beattock . . . . . . . | | | | | | | |
| | 34 | 61 | 33·4 | — | ·23 | 4 | 48 |
| Carstairs . . . . . . . | | | | | | | |
| | 15·5 | 30 | 31 | 11·25 | — | 3 | 43 |
| Motherwell . . . . . . . | | | | | | | |
| | 12 | 24 | 30 | 8·26 | — | | |
| Southside . . . . . . . | | | | | | | |

Coke consumed, 9 cwt. } steam already up.
Coal consumed, 2 cwt.
Water evaporated, 170 cubic feet.
Consumption per mile, { coke, 10·08 lbs.
coal, 2·24 lbs.
lbs. of fuel for each cubic foot of water evaporated, 6·1.

*Particulars of a Trip from Glasgow to Carlisle, 27th June,* 1849.

| STATIONS. | Miles. | Total time running. | Average speed per hour. | Average accelerating effect of a ton. | Average retarding effect of a ton. | Number of carriages. | Estimated weight of train, including engine. |
|---|---|---|---|---|---|---|---|
| | | Minutes. | Miles. | lbs. | lbs. | | Tons. |
| Southside | | | | | | | |
| | 2 | 9 | 13·3 | — | 10 | 7 | 63 |
| Rutherglen | | | | | | | |
| | 2 | 5 | 24 | — | 8·5 | | |
| Cambuslang | | | | | | | |
| | 3 | 9 | 20 | — | 4·8 | | |
| Uddingstone | | | | | | | |
| | 5 | 13 | 23 | — | 9·75 | 8 | 68 |
| Motherwell | | | | | | | |
| | 3 | 8 | 22·5 | — | 19·5 | | |
| Wishaw | | | | | | | |
| | 4 | 12 | 20 | — | 18·9 | | |
| Carluke | | | | | | | |
| | 1 | 6 | 10 | — | 21·1 | | |
| Braidwood | | | | | | | |
| | 5 | 10 | 30 | — | 4 | | |
| Lanark | | | | | | | |
| | 2·5 | 6 | 25 | 7·21 | — | | |
| Carstairs | | | | | | | |
| | 7 | 15 | 28 | — | 6·2 | 7 | 63 |
| Symington | | | | | | | |
| | 4 | 4 | 32·5 | 5·64 | — | | |
| Lamington | | | | | | | |
| | 4·5 | 19 | 15·7 | — | 7·46 | | |
| Abington | | | | | | | |
| | 5 | 9 | 33 | — | 8 | | |
| Elvanfoot | | | | | | | |
| | 13·5 | 22 | 36·8 | 17·2 | — | | |
| Beattock | | | | | | | |
| | 5 | 10 | 30 | 7 | — | | |
| Wamphray | | | | | | | |
| | 5·5 | 12 | 27·5 | 17·4 | — | | |
| Nethercleugh | | | | | | | |
| | 3 | 6 | 30 | — | 4 | | |
| Lockerbie | | | | | | | |
| | 6 | 13 | 27·7 | 1·93 | — | | |
| Ecclefechan | | | | | | | |
| | 3 | 7 | 25·7 | 2·6 | — | | |
| Kirtlebridge | | | | | | | |
| | 4 | 8 | 30 | 17 | — | | |
| Kirkpatrick | | | | | | | |
| | 4·5 | 9 | 30 | 11·2 | — | | |
| Gretna | | | | | | | |
| | 4·5 | 9 | 30 | — | 1 | | |
| Rockcliffe | | | | | | | |
| | 4 | 9 | 26·6 | — | 6 | | |
| Carlisle | | | | | | | |

Coke consumed on trip (including getting up steam), 12 cwt.

Water evaporated, 214·6 cubic feet.

Consumption per mile, coke, 13·3 lbs.

lbs. of fuel for each cubic foot of water evaporated, 6·2.

Moderate breeze,—dry,—not much loss by safety-valves.

*Particulars of a Trip from Carlisle to Glasgow, 27th June,* 1849.

| STATIONS. | Miles. | Total time running. | Average speed per hour. | Average accelerating effect of a ton. | Average retarding effect of a ton. | Number of carriages. | Estimated weight of train, including engine. |
|---|---|---|---|---|---|---|---|
| | | Minutes. | Miles. | lbs. | lbs. | | Tons. |
| Carlisle . . . . . . . . | | | | | | | |
| | 4 | 10 | 24 | 6 | — | 7 | 63 |
| Rockcliffe . . . . . . . | | | | | | | |
| | 4·5 | 10 | 27 | 1 | — | | |
| Gretna . . . . . . . . | | | | | | | |
| | 4·5 | 12 | 22·5 | — | 11·2 | | |
| Kirkpatrick . . . . . . . | | | | | | | |
| | 4 | 9 | 26·6 | — | 17 | | |
| Kirtlebridge . . . . . . . | | | | | | | |
| | 3 | 10 | 18 | — | 2·6 | | |
| Ecclefechan . . . . . . . | | | | | | | |
| | 6 | 15 | 24 | — | 1·93 | | |
| Lockerbie . . . . . . . | | | | | | | |
| | 3 | 8 | 22·5 | 4 | — | | |
| Nethercleugh . . . . . | | | | | | | |
| | 5·5 | 15 | 22 | — | 17·4 | | |
| Wamphray . . . . . . . | | | | | | | |
| | 5 | 15 | 20 | — | 7 | | |
| Beattock . . . . . . . | | | | | | | |
| | 13·5 | 41 | 19·7 | — | 17·2 | | |
| Elvanfoot . . . . . . . | | | | | | | |
| | 5 | 14 | 21·4 | 8 | — | | |
| Abington . . . . . . . . | | | | | | | |
| | 8·5 | 17 | 30 | 5 | — | | |
| Symington . . . . . . . | | | | | | | |
| | 7 | 14 | 30 | 6·2 | — | 4 | 48 |
| Carstairs . . . . . . . . | | | | | | | |
| | 2·5 | 6 | 25 | — | 7·21 | | |
| Lanark . . . . . . . . | | | | | | | |
| | 6 | 11 | 32·7 | 4 | — | | |
| Carluke . . . . . . . . | | | | | | | |
| | 4 | 9 | 26·6 | 20 | — | | |
| Wishaw . . . . . . . . | | | | | | | |
| | 3 | 7 | 25·7 | 19·5 | — | | |
| Motherwell . . . . . . . | | | | | | | |
| | 5 | 10 | 30·8 | 9·7 | — | | |
| Uddingstone . . . . . | | | | | | | |
| | 7 | 15 | 28 | 8 | — | | |
| Southside . . . . . . . | | | | | | | |

Coke consumed, 13 cwt. } steam already up.
Coal consumed, 2 cwt. }
Water evaporated, 243·9 cubic feet.
Consumption per mile, coke, 14·4 lbs.
" " coal, 2·2 lbs.
lbs. of fuel for each cubic foot of water evaporated, 6·8.
Strong breeze and rain,—not much loss by safety-valves.

*Particulars of a Trip from Glasgow to Carlisle, 29th June,* 1849.

| STATIONS. | Miles. | Total time running. | Average speed per hour. | Average accelerating effect of a ton. | Average retarding effect of a ton. | Number of carriages. | Estimated weight of train, including engine. |
|---|---|---|---|---|---|---|---|
| | | Minutes. | Miles. | lbs. | lbs. | | Tons. |
| Southside | | | | | | | |
| Uddingstone | 7 | 16 | 26·25 | — | 7·7 | 7 | 63 |
| Motherwell | 5 | 12 | 25 | — | 9·75 | | |
| Lanark | 13 | 30 | 26 | — | 15·8 | 8 | 68 |
| Carstairs | 2·5 | 6 | 25 | 7·21 | — | | |
| Symington | 7 | 17 | 24·7 | — | 6·2 | 7 | 63 |
| Abington | 8·5 | 19 | 26·8 | — | ·91 | | |
| Beattock | 18·5 | 36 | 30·8 | 4·6 | — | | |
| Lockerbie | 13·5 | 32 | 25·3 | 6·8 | — | | |
| Ecclefechan | 6 | 14 | 25·7 | 1·93 | — | | |
| Gretna | 11·5 | 20 | 34·5 | 10·2 | — | | |
| Carlisle | 8·5 | 16 | 31·8 | — | 3·5 | | |

Coke consumed on trip (including getting up steam), 12 cwt.

Water evaporated, 197 cubic feet.

Consumption per mile, coke, 13·3 lbs.

lbs. of fuel for each cubic foot of water evaporated, 6·8.

Weather wet to Lockerbie,—dry from Lockerbie to Carlisle,—breeze moderate,—not much loss by safety-valves.

*Particulars of a Trip from Carlisle to Glasgow, 29th June,* 1849.

| STATIONS. | Miles. | Total time running. | Average speed per hour. | Average accelerating effect of a ton. | Average retarding effect of a ton. | Number of carriages. | Estimated weight of train, including engine. |
|---|---|---|---|---|---|---|---|
| | | Minutes. | Miles. | lbs. | lbs. | | Tons. |
| Carlisle | | | | | | | |
| Gretna | 8·5 | 19 | 26·8 | 3·5 | — | 11 | 83 |
| Ecclefechan | 11·5 | 25 | 27·6 | — | 10·2 | | |
| Lockerbie | 6 | 13 | 27·7 | — | 1·93 | | |
| Beattock | 13·5 | 32 | 25·3 | — | 6·8 | | |
| Abington* | 18·5 | 39 | 28·4 | — | 4·6 | | |
| Symington | 8·5 | 23 | 22·1 | ·91 | — | | |
| Carstairs | 7 | 13 | 32·3 | 6·2 | — | 9 | 73 |
| Lanark | 2·5 | 8 | 18·7 | — | 7·21 | | |
| Motherwell | 13 | 25 | 31·2 | 15·8 | — | 8 | 68 |
| Uddingstone | 5 | 10 | 30 | 9·75 | — | | |
| Southside | 7 | 15 | 28 | 7·7 | — | | |

Coke consumed on trip, 11 cwt. } steam already up.
Coal consumed „ 2 cwt. }

Water evaporated, 238·2 cubic feet.

Consumption per mile { coke, 12·2 lbs.
{ coal, 2·22 lbs.

lbs. of fuel for each cubic foot of water evaporated, 6·1.

Weather fine,—breeze moderate,—not much loss by safety-valves.

* Assisted for 10 miles.

# DESCRIPTION AND SPECIFICATION

OF

# THE PASSENGER LOCOMOTIVE ENGINE 'WREKIN,'

CONSTRUCTED BY

MESSRS. BURY, CURTIS, AND KENNEDY,

OF LIVERPOOL,

FOR THE SHREWSBURY AND BIRMINGHAM RAILWAY COMPANY:

WITH THREE ELABORATE ENGRAVINGS.

## DESCRIPTION AND SPECIFICATION

OF

# THE PASSENGER LOCOMOTIVE ENGINE 'WREKIN.'

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### DESCRIPTION.

THE 'Wrekin,' which was constructed by Messrs. Bury, Curtis, and Kennedy, at the Clarence Foundry, Liverpool, is similar, in all the principal parts, to the 'Liverpool' locomotive engine, built at the same works, and placed on the Liverpool and Manchester Railway in July, 1830.

The 'Liverpool,' the first engine constructed with a cranked axle and horizontal cylinders, was employed in making the above line of railway: its performances were so highly satisfactory as to establish a confidence in the correctness of the principles and arrangement adopted; and the opinions then formed have been amply confirmed by subsequent experience.

The 'Liverpool,' it should be mentioned, was placed on four wheels; but the 'Wrekin,' being a heavier and more powerful engine, has six wheels.

One of the greatest advantages of the latter engine is derived from the framing being placed inside the wheels, the breadth-way of the framing, horizontally instead of vertically, having only two bearings to the axles; the axle-bearings being forged or bolted to the frame: the cylinders are also securely fixed to the frame, and the whole closely fixed on the body of the fire-box and boiler. The tender is directly coupled to the framing; and as no strain whatever is put on the boiler by means of the connection, it will be obvious that it becomes almost impossible to derange the lines of the engine by any ordinary concussion; the whole being so firmly bound together in one mass, that any violent agitation must equally affect all the parts, and thus prevent the derangement of any single part.

By this arrangement it is found that there is no necessity to key up the main bearings of the axles, as the insistent weight of the engine rests on the axle-bushes; and thus, notwithstanding the horizontal action of the engine on the cranked axle, the bushes never get play in the journal horizontally: therefore, in this part, no attention is required beyond cleaning and oiling.

The inside frame admits of the various parts of the engine being readily seen from the outside, either for the purpose of examining the machinery or for oiling; and the parts are so constructed that the whole may be easily taken to pieces when repairs become necessary.

Another advantage of the inside frame is, that when the gravity or insistent weight is placed inside the wheels, as in the 'Wrekin,' the weight of the engine has a tendency to press or bend down the axle between the bearings, which may be said to counteract the constant tendency arising from the flanges of the wheels pressing against the edge of the rails, more particularly in passing over curves.

## SPECIFICATION.

*Cylinders, Covers, and Valve-Boxes.*—The cylinders are 15 inches diameter and 20 inches stroke, placed in the smoke-box, and secured to the framing on each side by strong brackets cast on them, the cylinders themselves being fitted and firmly bolted together in the centre. Each cylinder is fitted with two cocks for letting out the condensed water, one at either end and one in the valve-box, which is common to both cylinders, with levers and rods carried forward to the foot-plate for opening and shutting: a grease-cup and cock are fitted in the bottom of each cylinder.

Steam-ports 12″ × $1\frac{5}{16}$″; exhaust ditto 12″ × $3\frac{1}{4}$″.

*Pistons.*—The pistons are fitted with two depths of packing, each depth consisting of one concentric ring of cast iron, with one circular steel spring and one wedge in each; the body and junk-ring of brass ;s teel bolts for junk-ring, tapped into the body of the piston: rods of best Yorkshire hammered iron, $2\frac{1}{8}$ inches diameter.

*Valves and Rods.*—Valves of brass, working on an angular face, as shown in the Plate; working part of rods of steel; travel of valves $4\frac{1}{2}$ inches; lap on steam side $1\frac{1}{8}$-inch; ditto on exhaust side $\frac{1}{32}$ inch; lead $\frac{3}{16}$ inch.

*Cross-Heads and Centre-Pins.*—Cross-heads forged of the best hammered iron, and firmly cottered to the piston-rod, with two split-pins through the end of the cotter, to prevent its coming out. The centre is secured in its place by the cross-head being heated and shrunk on to it. The outside end of this pin is lengthened out, and to which the ram for working the pumps may be attached.

*Slide-Bars, Blocks, and Hangers.*—The slide-bars are double, that is, one on each side of each piston-rod, of best hammered iron, lined on the working face with steel: the slide-blocks are of hard brass, with tongue-pieces cast on them, which work into corresponding grooves in the top and bottom slide-bars.

The hangers or spectacle eyes, to which the ends of the guides are bolted, are carried by a cross-stay from the framing. The hangers are tied together at the bottom by a stay going between them.

*Pumps and Rams.*—The pumps are of brass, with brass rams; the heads are of wrought iron, secured to the ram by a wrought-iron pin, cottered at one end into the ram, and at the other into the ram-head.

The valves and seats are of brass, and of a kind known as conical valves.

*Connecting-Rods.*—The connecting-rods are forged of the best hammered iron, and are single at both ends.

The steps are of good hard brass, and fitted with double gibs and screwed cotters at both ends.

*Eccentric Rods and Straps.*—The eccentrics are in two halves (of cast iron), and secured to the crank-axle by one key through the whole four eccentrics, and a set-screw in each. The straps are of brass also, in two halves, bolted together with strong flanges. The rods are of best hammered iron, and are bolted to a flanged piece cast upon the eccentric strap, and at the other end are attached by pins to the valve quadrants.

Throw of eccentrics $4\frac{1}{2}$ inches.

*Valve Motion, Quadrants, &c.*—The valves are worked by what is termed the 'quadrant' or 'link' motion, the quadrants being double, with the valve-link working between. The blocks in the quadrants are of best hammered iron, case-hardened. The shaft which carries the reversing levers, and balance weights, &c., is hung from brackets or snugs, welded solidly to the framing at the point. The reversing handle works in a quadrant guide, bolted on the foot-plate, with notches cut in to suit the various grades of expansion.

*Framing and Stays.*—These consist entirely of the best hammered iron bars, welded together in the manner shown in the Plate, and well and securely fitted to the fire-box and smoke-box at the ends, and through the stays to the barrel of the boiler. The driving and trailing wheel pedestals are welded solid with the framing; the leading wheel pedestals being bolted and firmly secured to the framing by keys.

*Wheels, Axles, and Axle-Boxes.*—The driving wheels are 5 feet 6 inches in diameter; the leading-wheels are 4 feet in diameter; the trailing-wheels are 3 feet 6 inches in diameter; all with cast-iron naves, with wrought-iron welded spokes and rims (the spokes cast solid into the nave), and hooped with tires 2 inches thick when finished.

The axle-boxes are of good hard brass, well fitted to the pedestals, and truly bored to suit the journals of the axles. The top part of the axle-box is cored out to form a grease-box, and is covered with a hinged lid.

The name-plates on the centre of the axles are of brass, secured by a pin tapped into the axle.

*Springs.*—The driving wheel springs have fourteen plates (namely, one $\frac{1}{2}$-inch, and thirteen $\frac{7}{16}$-inch), $3\frac{1}{2}$ inches broad.

The leading wheels have twelve plates (one $\frac{1}{2}$-inch, and eleven $\frac{7}{16}$-inch), $3\frac{1}{2}$ inches broad.

The trailing wheels have eight plates (one $\frac{1}{2}$-inch, and seven $\frac{7}{16}$-inch), $3\frac{1}{2}$ inches broad.

All the spring links have screwed ends, to attach to the framing, with double jam-nuts, and a pin through the screw.

*Boiler and Outside Shell of Fire-Box.*—The barrel of the boiler is constructed of the best Staffordshire plates, and the outside shell of the fire-box of best Yorkshire plates, of the dimensions and form shown in the Plate. The fire-box is of copper, the tube-plate bare $\frac{3}{4}$ inch thick, the rest $\frac{1}{2}$ inch full thick, properly stayed on the top and at the sides with best wrought-iron stays, as shown.

Heating surface in fire-box 80 square feet.

Area of fire-grate 15 square feet.

*Tubes.*—The tubes are of brass, one hundred and seventy-two in number, 11 feet 6 inches long, $2\frac{1}{8}$ inch full diameter outside, No. 13 wire-gauge thick at fire-box end, and No. 14 wire-gauge thick at smoke-box end. The tubes are secured in the tube-plates by annealled cast-iron ferrules, well mandrilled at both ends.

| | |
|---|---|
| Heating surface in tubes . . . . . . . . | 1059 square feet. |
| Do. in fire-box and tubes . . . | 1139 „ |

*Smoke-Box and Chimney.*—Smoke-box $\frac{5}{16}$ inch thick, and chimney $\frac{3}{16}$ inch thick, of best Staffordshire plates: chimney-top of copper, 6 lbs. per foot: height of chimney from top of rails 13 feet: one handle in centre of smoke-box door, with three lock-bolts.

*Buffers.*—The buffers are of leather, well stuffed with curled horse-hair, and secured to the buffer-beam by wood screws: the buffer-beam is of well-seasoned oak, 14″ × 7″. Distance between the centre of buffers 5 feet 9 inches; height from rails to centre 3 feet 3 inches. The buffers are fitted with a guide-spindle, working in a bush in the buffer-beam: a draw-chain and hook are bolted through the centre of the buffer-beam.

*Main Steam-Pipe and Regulator, &c.*—The main steam-pipe in the barrel of the boiler is an iron tube, with a slit $\frac{3}{16}$ of an inch wide along the top of it: the rod from the regulator handle passes through the centre of the pipe to the regulator valve in the smoke-box. The valve and valve-box are of brass: the valve is a double-beat, or equilibrium valve, and is opened and shut by means of a coarse three-threaded screw, formed upon the end of the valve-spindle working into a nut upon the valve-box bonnet.

*Branch, Steam, and Blast Pipes.*—The branch, steam, and blast pipes are of copper, and the steam-pipes are bent round on each side to clear the tubes. The blast-pipe is formed of two $5\frac{1}{4}$-inch pipes from the cylinder, joined into one tapering pipe, $4\frac{1}{4}$ inches diameter at top, which terminates within 2 inches from the level of the bottom of the chimney.

*Suction-Pipes from Pumps, &c.*—The suction-pipes from the pumps and feed-pipes to the boiler are of copper; the coupling-pipes between the engine and tender are of brass, with ball and socket-joint, properly carried with wrought-iron hangers, brackets, &c.

*Hand-Rail and Foot-Plate.* — The foot-plate is of the best Staffordshire iron, $\frac{5}{16}$ inch thick, well fitted and secured to the framing. The hand-rails are of wrought iron, with brass knobs; the sides filled in with the best Staffordshire sheet iron, No. 13 wire-gauge thick.

*Felting, Lagging, &c.*—The barrel of the boiler is covered with a coating of No. 3 hair-felt, lagged with timber, and then lined over all with sheet iron, No. 17 wire-gauge thick, secured by wrought-iron hoops, bolts, and nuts. The outside shell of the fire-box is felted and lagged in the same manner; and round the front edge and the junction with the barrel of the boiler a strip of polished brass is fitted to make a finish. There is also a brass moulding round the smoke-box end of the barrel of the boiler.

*Painting, &c.*—The engine is painted with two coats of the best paint, and finished with a coat of the best copal varnish.

# Division A.—Locomotive Engines.

## Ninth Paper.

# DESCRIPTION

OF

# THE FIRST-CLASS EXPRESS ENGINE

MADE BY

R. & W. HAWTHORN, OF NEWCASTLE-UPON-TYNE, NOVEMBER, 1849.

Plate I. represents a side elevation of the engine and tender.

Plate II. is a longitudinal section of the engine and tender.

Plate III. is a plan of the engine and tender.

Plate IV. is a plan of the engine, with the fire-box in section; also the smoke-box and other parts of the boiler removed, in order to show the arrangement of the machinery beneath it.

The Fire-Box, B, is made entirely of copper plates ½ inch thick, except the tube-plate, which is ⅞ inch thick where pierced for the tubes; the other portion of the plate being reduced to the same thickness as the other plates. The top and sides of the fire-box are formed of three plates, and the front and tube-plate have their edges turned inward to form flanges, to which the outer plates are riveted by ¾-inch copper rivets, 1¾-inch centres. The fire-box is fastened at the bottom to the fire-box casing, A, by a wrought-iron plate worked into the shape of a double angle-iron, as seen in the longitudinal section, Plate II., and riveted to the fire-box and fire-box casing by ¾-inch rivets, 1¾-inch centres. The top of the fire-box being flat, requires being particularly well supported; and this is effected by eight strong beam-bars, C, Plate II., extending the full length of the box, with their ends resting on the end plates of the fire-box. There are eleven 1-inch bolts passed through each of these beams, with their ends screwed into the top plate of the fire-box, and a nut put on inside the plate, with the end of the bolt cut off flush with the face of the nut, and then hammered over a little, to prevent the possibility of shifting. There is a clear space between the top of the box and the under side of the beam-bars, 1 inch at the ends and 1½ inch at the middle (see Plate II.), to allow the free circulation of the water over the whole surface of the plate forming the top of the fire-box. The sides and ends of the fire-box are firmly secured to the fire-box casing by ⅞-inch copper bolts, placed 4¼ inches centres: these bolts are screwed the whole of their length, inserted into holes tapped through both plates, and riveted up at both ends, to keep them steam-tight and prevent their getting loose.

The Fire-Box Casing, A, is made of iron plates; the circular top is 7/16 inch thick, the ends and sides ½ inch thick. The form of the fire-box casing is clearly seen in Plates II. and IV.; it is made sufficiently large to allow 3 inches of water space at the front end and sides of the fire-box, and 3½ inches water space at the end next the boiler, where the heat is most intense. The top of the fire-box casing is tied to the two middle beam-bars on the top of the fire-box by two stay-rods, 1¼ inch in diameter, as seen in Plate II. The fire-door, *b*, Plate II., affords access to the fire-box for the introduction of coke; it is of an oval shape, 14 inches wide by 11 inches high: the space between the fire-box and fire-box casing is filled by an iron ring, formed into the shape of the door, and securely riveted through both plates, and the fire-door itself is furnished with an iron baffle-plate riveted to the inside, at a distance of 2 inches, to save it from the action of the fire within. The fire-box casing is fixed to the end of the cylindrical part of the boiler by a strong 3½-inch angle-iron, and the top is concentric with the boiler. The end plates have their edges turned inwards to form flanges, to which the sides are riveted by ¾-inch rivets, 1¾-inch centres.

The Boiler (E, Plate III.) is 10 feet 8 inches long, oval-shaped, 4 feet high by 3 feet 10 inches wide outside. The shape of the boiler renders lateral stays necessary to resist the pressure of the steam on the flat sides: these stays, *f f*, are seen in Plate II.; they are four in number, and 2-feet centres, to take up as little room as possible (as they have to pass between the tubes). They are made of plates 7/16 inch thick, 10 inches broad at the ends, and 6 inches broad at the middle, and are securely fixed to the boiler by strong angle-irons. The boiler is put together in the usual way, with overlap joints 2¼ inches broad and ¾-inch rivets, 1¾-inch centre: the plates are 7/16 inch thick.

Tubes (*ee*, Plate II.).—The boiler contains 229 brass tubes, 1¾ inch diameter outside, and No. 13 wire-gauge at the fire-box end, and 1⅞ inch diameter inside, and No. 14 wire-gauge at the smoke-box end. These tubes are inserted into the tube-plate of the fire-box, which is made thicker at that part, so as to afford a better bearing for the fixing of the tubes and insure sufficient strength: at the front extremity of the boiler they pass through a similar plate of iron, which forms the partition between the boiler and the smoke-box. In the fire-box plate the tubes are secured by driving a mandril tight into the end, so as to make them fit close against the surface of the holes in the plate; the ends of the tubes are then riveted over the edge of the holes, which is slightly counter-sunk, after which steel hoops or 'ferrules,' $\frac{1}{16}$ inch thick, and accurately turned, with a little taper, are driven firmly into the interior of the tubes, so as to render them perfectly steam-tight: the tubes are secured into the iron plate at the smoke-box end in a similar manner, except that there are no 'ferrules' or hoops. It was formerly customary to drive ferrules into each end of the brass tubes; but it has been found by experience that one ferrule at the fire-box end is quite sufficient to hold the tube in its place. Doing away with these ferrules facilitates the replacing of a faulty or worn-out tube, to a great extent. Another advantage of great importance is, that the tubes are much less liable to get choked with dust and cinders, and much easier to clean out when the ferrules in the smoke-box end are done away with; because whatever pieces of coke are forced into the tubes at the fire-box end, by the force of the blast, meet with no obstruction to prevent them passing through the tubes into the smoke-box.

The Smoke-Box, F, is for the purpose of collecting the gases evolved by the combustion of the fuel, which is conveyed from the fire-box, B, Plate II., into it by the brass tubes *e e*, and from thence transmitted through the chimney, G, into the atmosphere. In the smoke-box are also placed the steam regulator, blast, and steam-pipes for the supply of the cylinders; the front of the smoke-box is furnished with a large circular door, *g*, hinged on one side, and fitted air-tight to it; the door is provided with a handle in the centre, which is clearly seen in Plates II. and III.; the cross end of the handle passes through the door into a small circular plate which is secured to the handle: there are three sneck-bolts attached to this plate, and radiating towards the door-frame, which is composed of $1\frac{3}{4}$-inch angle-iron, into which three holes are made to receive the ends of the snecks; and by moving the handle these snecks are thrust into or drawn out of the holes, as the door may be required to be shut or opened: this door affords access for the insertion, repairing, and cleaning of the tubes, and also for the examination of the other parts referred to above. The iron tube-plate, already referred to, forming the partition between the boiler and the smoke-box, has its edges turned inward to form flanges; the edge of the plate forming the front of the box is turned in a similar manner, and to these flanges the side plates of the smoke-box are riveted by $\frac{5}{8}$-inch rivets and 2-inch centres: the side and front plate of the smoke-box are $\frac{5}{16}$ inch thick, and the plate forming the door $\frac{3}{16}$ inch thick; the smoke-box is fixed to the end of the boiler by a strong $3\frac{1}{2}$-inch angle-iron, in a similar manner to the fire-box casing.

Safety-Valves and Boiler-Mounting.—Although it is necessary to the efficient working of the engine that the boiler be capable of generating steam of a high elastic force, it is yet essential to safety that the steam pressure be confined within certain limits. In order to insure this, the boiler is provided with two safety-valves (*h*, Plate II.), both placed in one box fixed on the top of the fire-box casing, and surmounted by a polished brass chimney (H, Plate I.), of a form corresponding with that of the large chimney, G: both of these valves are what are called 'lever safety-valves,' one of which can be regulated to any degree of pressure between 1 ℔. and 120 ℔s. per square inch by the engine-driver; the other valve is adjusted to a pressure of 120 ℔s., being the maximum which the boiler is calculated to resist with perfect safety, and thus preventing the engine-driver at any time exceeding the above pressure.

To indicate the height at which the water stands in the boiler, and to enable the driver to keep it always at its proper level, two gauge-cocks, *n′ n′*, are screwed into the side of the fire-box casing, and a glass gauge-tube, communicating with the water inside, is fixed on the end of the fire-box casing, facing the engine-driver when standing on the foot-plate. A graduated scale is fixed behind the glass tube, and the required level of the water may thus be maintained with the greatest accuracy. An 'ordinary whistle,' *k*, is placed on the top of the fire-box casing, within reach of the engine-driver when standing on the foot-plate. Another whistle, *l*, generally called a 'guard's whistle,' is placed on the top of the fire-box casing, immediately behind the safety-valve cover, and a rod carried forward from the handle thereof to the front of the fire-box casing, to be within reach of the engine-driver. Between the driving and trailing wheels, and at the lowest extremity of the fire-box casing, are situated the blow-off cocks, *m*, one on each side of the fire-box casing: a rod is carried from the keys of these cocks up to the foot-plate, with a handle on the top, so that the engine-driver can open them without coming off the foot-plate. These cocks are for the purpose of emptying the boiler of water when required, and also for the purpose of cleansing it of the accumulation of sediment which is constantly being formed in it when the engine is in operation: the fire-box is provided with mud-holes, seen in Plates II. and IV., one placed in each corner of the fire-box casing, and a similar mud-hole in the smoke-box and fire-box immediately below the tube. These mud-holes are secured when the engine is at work by doors bearing against the inside of the boiler, and fixed each by a single bolt passing through a strong malleable-iron bridge bearing against the outside. After the hot water is blown off, the mud-hole doors are removed and the boiler allowed to cool: the jet of a pipe attached to a water-cock, with considerable pressure, (and placed in a convenient situation for the purpose,) is introduced into the mud-holes, so that all the mud, &c. that accumulates at the bottom of the water spaces round the fire-box, and also in the boiler, is effectually washed out: under ordinary circumstances, the boiler should be blown through every evening after the work of the day is completed, and washed at least every fortnight; but this of course depends entirely upon the quality of the water used for the engine.

STEAM-PIPES AND REGULATOR-VALVE.—The steam-receiver, *l*, is placed on the centre of the cylindrical part of the boiler, and is carried to a considerable height above it, in order that the mouth of the steam-pipe, J J, which opens into it, may be removed to as great a height as can conveniently be obtained, from the surface of the water in the boiler. The object of thus raising the open end of the steam-pipe is to prevent 'priming;' and as a further precaution against priming, an inverted cone, or 'baffle-plate,' made of sheet iron, is riveted to the interior of the steam-receiver, with an aperture in the centre, just wide enough to allow the free ascent of the steam between it and the steam-pipe which passes through it. The water in the boiler tends to prime only where there is a surface of metal to which it may adhere; consequently, when rising up the sides of the steam-receiver, it encounters the baffle-plate, which directs its course downwards and towards the centre, where, being unsupported, it falls back into the boiler. Should any priming occur round the sides of the steam-pipe itself, the water is in a somewhat analogous way diverted by the bell-mouthed shape of the pipe and returned to the boiler. The steam-receiver is surrounded by a cast-iron dome, I, which serves the very important purpose of diminishing the radiation of heat, by interposing a stratum of heated air between the steam-receiver and the atmosphere.

The steam-pipe, J,[1] is made of copper; the end of it (which is shown in section) enters an orifice in the regulator-box, K, which is accurately bored to receive it, and where it is made steam and water tight by driving an iron ferrule into the interior of the pipe, similar to those used for the tubes at the fire-box end. The steam regulator-box, K, is securely bolted to the exterior of the front tube-plate of the boiler; it has a door in front, which can be conveniently removed for examining and repairing the regulator-valve, *n*: the valve is opened and closed by the short arm seen on the end of the long rod, *o o*, traversing the whole length of the boiler and passing steam-tight through a stuffing-box in the back plate of the fire-box: a long handle, P, is fixed to the outer extremity of this rod, and the engine-driver is thereby enabled, with the greatest ease and precision, to regulate the supply of steam to the cylinders. A small pipe, screwed into the upper part of the regulator-box, rises through the smoke-box, and is surmounted by a brass cup, *q*, and provided with a stop-cock, by which oil may be admitted into the interior of the regulator-box for the lubrication of the working parts. The two branch steam-pipes, J J, Plate II., open a communication for the admission of the steam from the regulator valve-box, K, into the steam-chests, L L, and they are so disposed within the smoke-box as not to obstruct the cleaning or replacing of the tubes.

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[1] Although this description of steam-pipe with a dome is introduced in this engine, from a prejudice that has for some time existed against Messrs. R. and W. Hawthorn's steam-pipe, patented by them in November, 1839, the latter is now coming into general use on the principal southern lines of railway. It dispenses with the dome, and the prejudice against it being now overcome, there is little doubt of its superseding entirely (from its simplicity of construction) the original arrangement of steam-pipe and dome. The patent steam-pipe consists simply of a cylindrical tube extending from the smoke-box, close to the upper part of the boiler, to about the centre of the fire-box. It may be made of copper or iron, and the upper part is perforated with numerous small holes or longitudinal slits. These openings are made in such a manner as to admit the steam where it is generated, and thereby prevent its flowing off by the shortest direction, which would be the case if all parts were equally perforated: therefore, near the point of exit of the steam from the boiler only a small area of opening is used, gradually increasing as the distance from that point. This pipe may be made parallel or tapering towards the fire-box: it is introduced through the regulator from the smoke-box end, and is secured by driving a hoop into the interior of it, similar to the ordinary pipe: the fire-box end is closed up, and properly carried by hangers depending from the top of the boiler. It may be here remarked, that Mr. Gooch, of the Great Western Railway, has obtained licence from Messrs. R. and W. Hawthorn for the use of their patent steam-pipe for the engines on that line. Mr. Gooch extends the pipe from the regulator in the smoke-

CYLINDERS AND SLIDE-VALVES.—The cylinders (M M, Plate IV.) are 16 inches diameter, with a stroke of 20 inches; they are placed below the smoke-box, between the outside frames W and the inside frames *o o*, to which they are securely bolted, quite independent of the smoke-box: the slide-valves, *r r*, are placed outside of the cylinders, and there is a door upon each end of the steam-chest, which can be easily removed for the purpose of examining the valves, or taking them out for the purpose of being repaired; and the large door (L, Plate I.) on the side of the steam-chest can also be removed when the faces of the cylinders want grinding or planing. There are two holes in the door opposite the ends of the slide-valves, for the purpose of examining the lead, and setting the valve without taking off either of the steam-chest doors: these holes are 2 inches diameter, screwed and closed up by brass plugs, with neat canted heads on the outside.

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box to the front plate of the fire-box casing: he projects the stuffing-box for the regulator-rod (which is carried along inside the pipe) inwards, which serves the double purpose of carrying and closing the end of the pipe: this pipe is clearly seen by referring to the longitudinal section of the 'Iron Duke' locomotive engine. (See Plates, and also Part II. of 'Rudiments of Civil Engineering,' page 24, published by Mr. Weale, where the description of the above engine is given. It will further be seen by referring to the Plates of the 'Wrekin' locomotive engine, constructed by Messrs. Bury, Curtis, and Kennedy, of Liverpool, for the Birmingham and Shrewsbury Railway Company. By examining the longitudinal section of this engine, it will be seen that the pipe is only the length of the cylindrical part of the boiler, with one slit in the top side for the admission of the steam.

It will be seen by referring to Plate IV., that the position of the cylinders and valves admits of the boiler being placed as near the cranked axle as if the cylinders were placed outside, so that the distance between the centre of the cranked axle and the under side of the boiler is only 6 inches instead of from 16 to 22 inches, as is usual with inside-cylinder engines of the same length of stroke. This engine therefore combines the good qualities of the inside and outside cylinder engines, and is at the same time free from the 'lateral' and 'pitching' motion so much complained of in the latter class of engines at high speeds.

Framing, &c.—Having now given a general idea of the arrangements of the engine, the parts by which motion is communicated to the wheels must be explained. These are most distinctly delineated in the sectional elevation and plan, Plates II. and IV. To the front buffer-beam, *z z*, are bolted the inside frames, *o o*, which extend to the fire-box casing, where their ends are received into malleable-iron boxes riveted to the fire-box casing: the ends of the frame-bars are planed, and the box slotted out to secure a good but easy fit, and allow for the expansion and contraction of the boiler without undue strain on any of the working parts. These inside frames or bars serve the double purpose of imparting great strength and precision to the whole structure, and giving fixed points of resistance for the bearings of the working parts. Of these, the first part that claims attention is the piston-rods, P P, which are fixed into the pistons with a cotter in the usual manner, and at the opposite extremity are terminated each by a cross-head and guide-blocks, V, also attached to them by a cotter: into these guide-blocks are fixed the cross-heads, forming the bearings for the small ends of the connecting rods, Q. The guide-blocks are made of malleable iron faced with cast steel, formed with flanches accurately fitted and ground to the guide-bars, so as to work smoothly and steadily between them. These guide-bars are set truly parallel, and in the same plane with the centre of the piston-rods and cranked axle; they are firmly bolted to the cylinders at one end, and to a projecting bracket or steadiment at the other; and these are securely bolted to the inside frame-bars, *o o*; by which means the piston-rods are constrained to move in a truly rectilinear direction, and secured against any deflection or undue strain arising from the continual change of position of the opposite ends of the connecting rods, and in obedience to the revolutions of the cranks to which they are respectively attached.

The feed-pumps, S S, for the supply of water to the boilers, are also set in the line of the piston-rods, and the plungers partake of their motion, being each fixed to a projecting end on the cross-head, as seen in Plate IV. The arrangement of the pumps is fully shown in Plates II. and IV.; they are formed of cast iron with brass bushes and glands, and are firmly bolted to the inside framing, *o o*. The plungers, W, are of malleable iron $1\frac{7}{8}$ inch diameter, and at each stroke of the engine draw the water from the tender tank through the feed-pipe, *y*, and suction-valves, forcing it at the return stroke through the delivery and stop valve, *x*, into the boiler. These valves are prevented from rising out of their seats by stops fixed in the covers of their respective boxes, and so adjusted as to admit of their rising only to the proper height for the due ingress and egress of the water. A small cock, called the 'pet-cock,' is fixed to the outside of the stop valve box, and by means of a long slender rod the handle is brought within reach of the engine-driver, so that he may be enabled to ascertain at any time whether the pump is working efficiently.

The connecting rods, Q Q, are jointed, as before explained, to the cross-heads of the piston-rods. The coupling is effected in the usual way by means of straps, gibs, and cotters, properly secured against relaxing or falling out. The opposite ends are attached in the same manner to the cranks, R R, upon the axle of the driving wheels. This cranked axle is formed of the best fagoted scrap iron; the cranks being cut out of the solid mass, and the one set exactly at right angles to the other by twisting the straight part of the axle between the cranks.

ECCENTRICS AND VALVE-GEAR.—This engine is provided with four eccentrics,[2] *a a* and *b b*; the two first for the backward, and the others for the forward gear: the form of these eccentrics is partly shown in Plate I., and distinctly seen in plan in Plate IV.: each eccentric is formed in one piece of malleable iron, bored out and accurately fitted on a projection on the outside of the wheel boss for their reception, whereon they are firmly fixed by three pointed set-bolts. The forward eccentrics, *b b*, for both cylinders, are fixed on their seats a little in advance of a line at right angles with their respective cranks, for the purpose of giving the required lead; and the position of the backward eccentrics is adjusted upon the same principle, though of course on the opposite side of the cranks. The eccentric rods are bolted firmly to the brass straps surrounding the eccentrics, and their opposite extremities are connected to the ends of the expansive link, *c′*, by double eyes and pins, as seen in Plate IV.; the ends of the top pins are continued beyond the outside of the eccentric rod eye to receive the boss, *g*, of the suspension links; the bearing pins for the other end of the links are fixed into the carriage, *f*; and the expansion links vibrate backward and forward on these suspension links, instead of reversing them in the usual manner. The motion of the engine is reversed by the rods *d′ d′*, which form the connection between the expansion links and the slide-rods: the forked end of these rods is attached to the slide-rod by a moveable pin; the other extremity is provided with a double eye to receive the half of the expansive links, and the slides and the connection formed by passing a pin through the double eye and slider: the end of this pin is continued beyond the double eye to receive the boss of the lifting or reversing link: the other end of this link is fixed to the reversing arm keyed on the weigh-bar *e′*; and the inside of the expansion links is steeled and planed out to a radius equal to the length of the rod *d′*, to receive the steel slider. The reversing gear or mechanism by which the engine-driver is enabled to move the engine in either direction, consists of a system of rods and levers *e′ e′ e′*, commencing with the arm *e′*, on the weigh-bar, and terminating in a long handle placed on the foot-plate, by which the end of the rods *d′ d′*, to which the sliders are attached, can be shifted from one end of the expansive links to the other. The expansion or cutting off the steam is effected by removing the slider towards the centre of the link, thereby shortening the travel of the slide-valve *r*, and the amount of expansion is indicated on the sector forming the guide for the long reversing handle *e′*. There are three principal notches cut in the top edge of the sector-guide to receive the catch-pin seen on the back of the reversing handle: one of these notches is placed at each end of the sector-guide, and the other in the centre; those at the ends of the guide are for the forward and backward motion of the engine, and that in the centre for retaining the handle in that position after disengaging the working gear, and consequently stopping the engine: between the end and centre notches are cut three notches for the different degrees of expansion. The advantage to the engine-driver of this mode of reversing the engine is obvious, from having only the rods *d′ d′* to reverse, instead of having *all the weight* of the expansive links and eccentric rods to move every time he reverses his engine: besides, this arrangement of expansive links and rods retains the *lead* of the slide-valves entire, at whatever portion of the stroke the steam is cut off.

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[2] It may be here remarked that the Messrs. Hawthorn were the first that gave certainty of action to the slide-valves of the locomotive engine, by the introduction of four eccentric wheels, keyed fast upon the cranked axle of the engine, instead of the two eccentrics previously in use, working loose upon the axle, and depending upon the striking-in of clutches for directing and controlling the motion of the engine.

WHEELS AND OUTSIDE FRAMING.—The driving wheels, T T, are 7 feet in diameter, formed of malleable iron, with the boss, arms, and rim forged together in one solid piece. The tire, which is of the best material, is 2¼ inches thick and 5½ inches broad. These wheels are firmly fixed on the cranked axle, the ends of which are produced beyond the boss of the wheels, to form the bearings for the outside frames. The leading and trailing wheels, V V, are each 4 feet diameter, of similar construction and materials to the driving wheels, firmly fixed on their axles, the ends of which are produced beyond the boss of the wheels, to form the bearings for the outside frame, similar to those of the cranked axle. The rim of these wheels is accurately turned in the lathe, after being welded together.

The tires are also bored internally to a slightly smaller diameter than the rim, and shrunk on; they are then secured to the rim by a few tap-bolts, which are screwed about $1\frac{1}{4}$ inch into the tire, and the whole turned accurately to the proper form and diameter.

As the whole weight of the engine rests upon the wheels, it may be expected to suffer from jolting in passing over the irregularities of the rails: to obviate this as far as possible, the springs, *h' h'*, *i' i'*, are interposed, the former suspended from the inside bearing below the frame O O, and the latter from the outside bearing or axle-box, *k'*, of the main axle. The leading and trailing springs are placed above their axle-boxes, and between the two plates forming the outside frame, W W, so that they are not seen in either of the Plates. They are composed of thin layers of steel, gradually diminishing in length from the centre to the extremities, and bound together by connecting hoops, secured in their place by a small round pin passing through them and the steel plates: the connecting hoop is formed with an eye projecting upwards into the lower portion of the axle-box, where it is fixed by a round pin passing through it. The axle-boxes, *k' k' k'*, which are of cast iron fitted with brass bearings, slide up and down as the springs bend with the weight of the engine, between the cast-iron axle-box guides, which are accurately planed and fitted, and bolted firmly between the plates of the outside frame.

The axle-boxes are formed with a sort of reservoir for oil and tallow, which are constantly supplied to the rubbing surfaces by two small tubes and syphon-wicks. It may be here remarked that the other rubbing parts of the engine are lubricated in the same manner. The springs, *i' i'*, for the driving axles, are provided with adjusting links, by which means the weight that it may be thought expedient to throw upon these springs can be accurately adjusted. The external framing consists of two strong parallel beams, W W, extending somewhat beyond the engine at both ends, and connected in front by the wooden cross-beam or buffer-beam, Z Z, and behind by another beam, somewhat different in shape (see Plate IV.), on which rests the foot-plate, Y Y. These beams are firmly bound at the corners by angular plates of iron bolted through each, and the weight of the boiler is supported upon them by the strong malleable-iron brackets or stays, X X X, riveted to the boiler, and bolted through the outside frames, W W. These latter are formed each of two parallel plates of iron, cut out into the form shown in the general elevation, Plate I., with horns projecting downwards for the bearings of the wheels. Between each pair of plates, a beam of well-seasoned oak is interposed, and the whole firmly bolted together.

To deaden the shock to which the engine is exposed, it is provided with buffers, *m' m'*, fixed to and projecting in front of the buffer-beam, Z Z. These buffers are a species of elastic cushions, formed of horse-hair, surrounded by strong leather, and further strengthened by slender malleable-iron hoops. To secure the engine against the effects of the wheels coming in contact with stones or other obstacles which may happen to be lying on the rails, it is furnished with strong malleable-iron safeguards, *l′ l′*, descending from the buffer-beam to within a short distance of the rails, and so formed at the points as to turn aside any object with which they may come into collision.

Any water which may happen to accumulate in the cylinders, whether from the priming of the boiler or the condensation of the steam, and which, unless removed from time to time, would be very detrimental to the working of the engine, is let off by means of the waste water-cock, *q′*, communicating with the discharge passage of each cylinder. The easing-cock, *p′*, placed on the underside of the valve-boxes, serves the double purpose of easing the pressure of the steam from the valves in reversing the engine, and also letting off the water that may happen to accumulate in the valve-boxes when the engine is not running. The handles for these cocks are fixed on the foot-plate within reach of the driver, and are connected by a system of rods and levers, as seen by referring to Plates I. and III. Upon the front of the smoke-box, and near the top, is fixed a small stud for supporting the signal lamp, *v′*, by which notice is given at night of the approach of the engine and train.

As a precaution against accident to the engine-driver and his assistant, hand-rails, *s′ s′*, are erected on each side of the foot-plate Y, and these are continued along the whole length of the boiler and across the front of the smoke-box, so that they may be enabled, with comparative safety, to walk round the engine, even when it is in rapid motion.

When the engine is at rest, the steam, which would otherwise escape at the safety-valves and be thrown to waste, is made available for the heating of the water in the tender tank. This is accomplished by means of the heat-pipe, *o′*, by which a communication is made between the steam within the fire-box and the feed-pipe, *y*; and thereby a considerable saving of fuel is found to be effected.

The connection of the engine and tender is made by means of the strong coupling-screw, *t′*, one end of which is secured by a strong pin to the brackets or 'drag-plates,' which are securely riveted to the end of the fire-box casing under the foot-plate of the engine, while the other is in a similar manner joined to the buffer-spring of the tender. This coupling is composed of two strong double links, provided with nuts and joint pins at one end, to receive the right and left screw-bolt, by which means the tender is kept tight up against the centre buffer on the engine-frame, thus avoiding the jolting that is found to take place when there is nothing intervening between the engine and tender, as is the case with the ordinary single-link coupling. To guard against accident by the breaking of the coupling-screw, two strong safety-chains, *o o*, are provided, and placed one on each side of it. The arrangement of the coupling and safety-chains is clearly shown in Plates III. and IV. The connection between the engine and tender suction-pipes is formed by the coupling bras spipe *z z*, which is provided with ball and socket joints, and properly carried by malleable-iron hangers descending from the engine-frame: these joints are for the purpose of yielding when the engine is taking curves, or passing over uneven parts of the rails, and thereby preserving the suction-pipes from getting bent or broken.

To assist the engine-driver in rising into his place on the foot-plate, the foot-steps, $x' x'$, depend on each side of it, to within an easy distance from the ground.

### CONSUMPTION OF FUEL, EVAPORATION OF WATER, SPEED, AND LOAD.

The 'Plews' locomotive engine was the first constructed on the principles explained in the foregoing description: it was tried upon the York and Newcastle Railway, on the 28th of December, 1848, and is now running the express train four times a week from Newcastle to York and back. The second engine, and with which the following experiments have been made, is in every respect similar to the 'Plews,' and was put upon the North British Railway on the 5th of June, 1849. From the experiments made with the express and mail trains the consumption of coke and water was found to be as follows:

| | lbs. | | lbs. | |
|---|---|---|---|---|
| Coke consumed from Edinburgh to Berwick, computed a distance of 60 miles, | 925, | or | 15 | per mile. |
| From Berwick to Edinburgh . . . . . . . . . . . . . . . | 700 | „ | 11⅔ | „ |

Water evaporated both ways, 2640 gallons, or 22 gallons per mile.

It may be here observed, that the above is the consumption of coke and water during the time steam was on the pistons in traversing the distance, at an average speed of 40 miles per hour, with a train of 40 tons, exclusive of the engine and tender. By further experiments with this engine on the above railway, it was found that at a speed of 70 miles per hour, with a train of 35 tons, exclusive of the engine and tender, the average consumption of coke was about 16 lbs. per mile. The experiments were tried at the speed of 30, 40, 50, 60, and 70 miles per hour, with trains of 70, 65, 60, 50, and 40 tons, exclusive of the engine and tender; and the consumption of coke and water was found to be in a similar ratio per mile to the above.

During the foregoing experiments, great care had been taken to arrive at correct results by weighing the coke in a pair of scales as it was supplied to the engine, so that the results obtained may be relied upon as correct.

## DESCRIPTION OF THE TENDER.[1]

The tank, A A, consists of a rectangular sheet-iron cistern, capable of containing 1400 gallons of water for the supply of the boiler. It is made with a long recess, B, for the reception of coke, the species of fuel mostly in use for locomotive engines. The floor, *a*, of this recess is made with a slope downward from the front of the tender, by which arrangement the fuel is prevented from being thrown out by any jolting or shaking to which it may be subjected. Towards the back of the tank it is surmounted by a pipe or opening, C, by which water is introduced from the water-crane or other contrivance for that purpose. A cover is fitted over the opening when not in use. At the same place are fixed the tool-boxes, D D, for containing spanners and other implements which may be required for the engine. At the front of the tank, and on each side, are situated the cocks, *b b*, for regulating the supply of water to the suction-pipes, *c c*, communicating between the feed-pumps and the tender. These are connected to the feed-pipes, *y y*, by means of the brass ball and socket joint pipes, *z z*, already described, and screwed on to each by the union joints, *d d*, thus admitting of a considerable amount of vibration or change of position, without breaking the connection. The frames, E E, are of a similar form and construction to that of the engine. The outside plates of these frames are continued up 1½ inch above the rest of the frame, to receive the tank, which is closely fixed down between them, and riveted. The ends of the tank are steadied by the cross-beams, F F, which are continued up similar to the outside plate of the frames, thus fixing the tank firmly in its place without the necessity of bolts; and to prevent its starting up from any sudden concussion that it may be exposed to, a strong angle-iron is riveted to the back part of it, and resting on the cross-beam, F, to which it is firmly bolted: the ends next the engine are also secured by short pieces of angle-iron, riveted to the inside, and bolted to similar pieces, riveted to the inside framing, *e e e*, for their reception. The inside framing consists of iron plates 7 inches broad and ⅝ inch thick, firmly tied together by 3-inch angle-irons. To stiffen these plates, and form a good bearing for the bottom of the tank to rest upon, 3-inch angle-irons are riveted flush with the top edge, as seen on the plan, Plate IV., where the tank is removed to show more clearly the arrangement of the framing. The tender is supported upon six wheels and axles provided with axle-boxes, *f f f*, and springs similar to those of the leading and trailing wheels of the engine. The wheels are 3½ feet in diameter, and of the same construction and materials as those of the engine.

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[1] Messrs. R. and W. Hawthorn are now constructing engines of various sizes, principally for branch and short lines of railway, to carry their own supply of coke and water without a tender, generally called 'tank engines.'

The brake apparatus, clearly shown in Plates I. III. and IV., consists of a train of mechanism by which a great amount of friction can be simultaneously produced upon the peripheries of the tender-wheels, for the purpose of reducing the momentum of the engine and train when it is required to come to a stop. The handles, *h h*, are fixed to the upper extremity of the brake-rods, H H, working in a strong bearing attached to the tank; the lower portion of the rods is formed into a screw, and works through the malleable-iron nuts, I I, on which are formed double links, jointed at their lower ends to the brake levers. The latter have their centre of motion in the short shaft working in strong bearings attached to the inside framing, and which carries the double-toothed sector, J J. The longitudinal iron bars, K K, extend the whole length of the tender; and a small portion of each, towards the front extremity, is formed into a rack, so adjusted as to work into the teeth of the sectors, J J: the cranks, K, are supported and guided in their motion by small rollers working in the malleable-iron guides, *l l l*, and to these bars are bolted the angular-iron brackets which carry the wooden brake-blocks, *m m m*, by the contact of which with the exterior surface of the wheels the friction is produced.

By this arrangement, it is obvious that by screwing the vertical spindles, H H, into the nuts I I, the latter will be drawn upwards, and carrying with them the brake levers, the toothed sectors, J J, will be made to revolve upon their axis; and consequently the bars, K K, will be drawn each in the opposite direction to the other: each wheel will therefore be forcibly compressed between the brake-blocks, *m m m*, and the engine and tender proportionally retarded.

Where the tender is connected to the engine, the former is provided with a spring, *n*, having its centre of motion in the large round pin in the end of the drag-bolt socket, upon which it is caused to move by the buffer-bolts: when the engine and tender are going through curves, the ends of the spring are received and guided by saddles fixed on the end of the buffer-bolts for that purpose: these bolts work in iron guide-boxes fixed in the front beam of the tender, and so accommodate themselves to any inequality that may happen to take place between the engine and tender, and prevent sudden jolting by thus retaining an uniform pressure against the end of the engine-frame. Inside the cross-beam, F, is placed the drag-spring, *g*, the ends of which bear against the beam, whilst the drag-bolt, to which the train is coupled, is attached to the middle of it by a strong iron hoop provided with a socket, into which the drag-bolt is securely keyed. This spring is for the purpose of deadening the shock that would otherwise be given to the engine and train when starting suddenly.

For the accommodation of the engine-driver and stoker, the tender is furnished with foot-steps, *r r*, placed at an easy distance above the steps of the engine.

By these arrangements, and by the assistance of the hand-rails, *q q*, the foot-plate is rendered easily accessible.

At the extremity of the tender, the buffers, *p p*, similar in construction and situation to those formerly described, are fixed to the cross-beam of the framing, for the purpose of softening the shocks produced by the occasional irregularities of motion between the engine and the train.

---

### REFERENCES TO THE PLATES OF THE ENGINE.

| | |
|---|---|
| A A | Fire-box casing. |
| B | Fire-box. |
| C | Fire-box top-stays. |
| D D | Ash-box. |
| *a a* | Fire-box stays. |
| *b* | Fire-door. |
| *c c* | Fire-bars. |
| *d d* | Drop-bar gear. |
| E E | Boiler. |
| *e e* | Tubes. |
| *ff* | Boiler stays. |
| F F | Smoke-box. |
| *g* | Smoke-box door. |
| G | Chimney. |
| H | Safety-valve cover, or chimney. |
| *h* | Safety-valves. |
| *i i* | Safety valve levers. |
| I | Steam receiver. |
| J J | Steam-pipe. |
| K | Regulator valve-box. |
| *j* | Water-gauge. |
| *k* | Common whistle. |
| *l* | Guard's whistle. |
| *m* | Blow-off cock. |
| *n* | Regulator slide. |
| *o o* | Regulator rod. |
| *p* | Regulator handle. |
| *q* | Oil cup for lubricating the regulator slide. |
| L L | Steam-chest. |
| M M | Cylinders. |
| N | Blast-pipe. |
| *r* | Slide-valve. |
| *s s* | Steam passages. |
| *t* | Exhaust passages. |
| *u* | Blast-pipe top (loose). |
| O O | Inside framing. |
| P | Piston-rod. |
| *v* | Cross-head and guide-block. |
| Q | Connecting rod. |
| *w* | Pump-ram. |
| *x* | Pump stop-valve. |
| *y y* | Suction-pipes. |
| *z z* | Ball and socket pipes. |
| R | Cranked axle. |
| S | Force-pump. |
| T T | Driving wheels. |
| U U | Fore do. |
| V V | Hind do. |
| W W | Outside framing. |
| X X X | Stays for supporting the boiler upon the frame. |
| Y Y | Foot-board. |
| Z | Buffer-beam. |
| *a' a'* | Backway eccentrics. |
| *b' b'* | Foreway do. |
| *c' c'* | Coupling or expansion links. |
| *d' d'* | Slide-rods. |
| *e' e' e'* | Reversing-arm, weigh-bar, and rod. |
| *f' f'* | Weigh-bar carriages. |
| *g' g'* | Suspending links. |
| *h' h'* | Springs upon the inside frames. |
| *i'* | Springs upon the outside frames. |
| *j'* | Nuts for adjusting the weight upon springs. |
| *k' k' k'* | Axle-boxes. |
| *l' l'* | Safeguards. |

## REFERENCES TO THE ENGINE—*continued.*

| | |
|---|---|
| *m m* | Buffers. |
| *n n* | Water-gauge cocks. |
| *o o* | Heating-cock and pipe. |
| *p* | Steam-chest easing-cock. |
| *q* | Waste-water cock. |
| *r* | Pet-cock. |
| *s* | Hand-railing. |
| *t* | Screw-coupling. |
| *u* | Easing-cock handle. |
| *v* | Signal-lamp. |
| *w* | Steam-chest casing. |
| *x* | Foot-steps. |

## REFERENCES TO THE TENDER.

| | |
|---|---|
| A A | Water tank. |
| B | Coke-box. |
| C | Opening into tank. |
| D | Tool-box. |
| E E | Outside framing. |
| F F | Buffing-beams of the frame. |
| G G G | Wheels. |
| H H | Screwed rod for working the brake. |
| I | Nut-link for connecting the rod with the arm upon the— |
| J | Weigh-bar. |
| K | The cranks. |
| K K | Longitudinal bars. |
| *a* | Floor of coke-box. |
| *b b* | Water-cock handles. |
| *c* | Suction-pipes. |
| *d* | Union joints. |
| *e e e* | Inside framing and stays. |
| *f f f* | Axle-boxes. |
| *g* | Drag-spring. |
| *h* | Handles for brake. |
| *j* | Double sector, for working nut the — |
| *k k* | Brake-bars. |
| *l l l* | Guide-roller carriages, for supporting the brake-bars. |
| *m m m* | Wooden brake-blocks. |
| *n* | Buffing-spring. |
| *o o* | Safety-chains. |
| *p p* | Buffers. |
| *q* | Hand-rail. |
| *r r* | Foot-steps. |

# DIVISION A.—LOCOMOTIVE ENGINES.

TENTH PAPER.

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## DESCRIPTION AND SPECIFICATION

OF

## CRAMPTON'S PATENT LOCOMOTIVE ENGINE 'LIVERPOOL.'

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THE 'Liverpool' has the largest amount of evaporating power of any locomotive engine upon any gauge. At the time the question of the gauges was being discussed, the London and North Western Railway Company instructed Mr. Crampton to superintend the construction of a locomotive equal in power to the largest in use on the Great Western Railway, for the purpose of proving that engines of very large power could be constructed for the narrow gauge, combining steadiness with a judicious arrangement of the working parts; however desirable it might be, for various reasons, to use small engines generally.

The 'Liverpool' was constructed by Messrs. Bury, Curtis, and Kennedy; it is supported on eight wheels, and contains 2290 feet of heating surface, being about 200 feet more than that of the 'Iron Duke,'—the largest engine on the broad gauge.

The principal difference in the arrangement of this engine consists in placing the driving axle behind the fire-box, by which the height of the centre of gravity is reduced to a greater comparative extent than in engines on the broad gauge, having the axle of the driving wheel under the barrel of the boiler. By relieving the weight from the centre wheels, perfect steadiness when running at high velocities is insured.

The working of the 'Liverpool' has fully confirmed the anticipations that were formed of its powers. The inducements which prompted the order to be given having subsided at the time of its completion, no elaborate series of experiments were instituted, similar to those made on the broad gauge: from extensive observation, however, it has been apparent that more power could with safety be employed upon the narrow gauge than was consistent with a due regard to economy; as the power and weight required to produce excessive speeds were found to be detrimental to the permanent way of all railways. With the ordinary heavy trains, the performances of the 'Liverpool' were highly satisfactory, taking a load with great ease, which required two and sometimes three engines of the ordinary power. Among other feats, the 'Liverpool' brought the train which conveyed Franconi's troupe and horses, consisting of forty carriages, from Rugby to the Euston terminus, and saved time between the stations; while it required three engines of the usual size to propel the same train from Liverpool to Rugby, and which, notwithstanding this seeming increase of power, lost time between the stations.

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## SPECIFICATION.

*Framing.*—The framing consists of two wrought-iron plates 1¼ inch thick, extending the whole length of the engine; to these are bolted transverse plates also 1¼ inch thick, fixed as follows: one at each end of the double longitudinal framing; two immediately behind the fire-box, to receive the bearings of the driving axle; two underneath, which follow the curve of the barrel of the boiler, and serve not only to add great rigidity to the framing at that part, but also form a convenient cradle on either side, to receive the cylinders: there is also another plate placed between the two front axles, and one at the extremity of the longitudinal double framing, which forms the 'buffer-beam' of the engine. Those under the barrel of the boiler are strengthened by means of angle-iron, as best seen in the longitudinal section.

*Boiler.*—The barrel of the boiler is designed to receive the largest possible number of tubes, and is constructed of the best Staffordshire plates. Referring to the transverse section, it will be seen that the upper part is a portion of a circle of larger diameter than the lower part; but the weakness of this irregularity of form is fully compensated by a series of transverse tie-bolts 1⅛ inch diameter, and 8 inches apart from centre to centre: the centre-line of these ties is 2 feet 2½ inches from the bottom of the body of the boiler. The horizontal and vertical seams are overlapped by a belt, firmly riveted by double rows of rivets.

*Outside Fire-box.*—The outside fire-box is swollen or bulged out at that part where it unites with the barrel of the boiler; and the lower part under the driving axle is extended 10 inches, for the purpose of increasing the amount of fire-grate surface.

*Inside Fire-box.*—The inside fire-box is constructed of copper, and is provided with a mid-feather or water space, the lower part of which is 7 inches from the surface of the fire-bars. The whole of the inside fire-box is securely stayed both at the top and sides, as shown in the longitudinal and transverse sections.

*Fire-grate.*—There are forty-four fire-bars, the area of which is 21·58 feet.

*Tubes.*—There are 292 brass tubes of $2\frac{3}{16}$ inches diameter and 8 of 1¾ inch diameter, 12 feet 6 inches in length: these tubes are fixed perfectly tight by means of iron ferrules at the smoke-box end, and steel ferrules at the fire-box end. The total heating surface of the tubes amounts to 2136·117 feet, and the heating surface of the fire-box amounts to 154·434 feet.

*Smoke-box.*—The smoke-box is made of the best Yorkshire plates; the front plate is supported by and secured to the double framing, and is provided with doors having proper fastenings, as seen in the end view.

*Chimney.*—The smoke-box is surmounted by a chimney 18 inches internal diameter, and 13 feet 2 inches high from the level of the rails; it is parallel throughout: the plate at the upper part, which is splayed, is simply added to form an appropriate finish.

*Damper.*—There is a damper, constructed after the manner of a Venetian blind, fixed in the smoke-box, at the end of the tubes: this damper is provided with a counter-balance weight and levers, as seen in the longitudinal section.

*Wheels.*—All the wheels are made entirely of wrought iron: the driving wheels are 8 feet diameter, having bosses 17 inches diameter; the fore-wheels are 4 feet 3 inches diameter, and the two pair of intermediate wheels are 4 feet diameter.

*Axles.*—The driving axles are 7 feet diameter, with bearings 10 inches long; the other axles are 6 inches diameter, and have bearings also 10 inches in length.

*Axle-boxes.*—The axle-boxes are of the form shown in the several views, and are made of good hard brass; they are well fitted to their various pedestals, and accurately bored to receive the journals of the axles.

*Springs.*—The springs are constructed in every respect similar to those represented in the Plates: it may be observed, however, that the weight of the fore part of the engine is equally distributed upon the four front wheels; and this is effected by means of a pair of springs, each spring having twelve plates, as best seen in the longitudinal section.

*Cylinders.*—The cylinders are 18 inches diameter, with a 24-inch stroke: they are cast free from every imperfection, and accurately bored to the required diameter: they are solidly fixed upon the transverse bearers, as before described. Each cylinder cover and bottom is provided with a cock, to aid the escape of any water which may have been formed by the condensation of the steam.

*Pistons.*—The pistons are fitted with metallic packing, consisting of two concentric rings of cast iron, each having a wedge and circular steel spring. The piston-rods are 2½ inches diameter, and are made of the best Yorkshire hammered iron.

*Valves and Boxes.*—The valves and boxes are formed as shown in the several views. The boxes have a communication on either side with the regulator by means of copper branch steam-pipes.

*Main Steam-pipe.*—The main steam-pipe is of wrought iron, 5 inches internal diameter, and 13 feet 6 inches long, having a slit ¼ inch wide along the top: it is suspended to the upper part of the interior of the barrel of the boiler.

*Blast-pipes.*—The blast-pipes are of copper, and extend from the valve-boxes along each side of the boiler, and through the sides of the smoke-box, in which they unite, and terminate in a line level with the bottom of the chimney; the diameter at that part being 5½ inches.

*Pumps and Rams.*—The pumps are of brass; the rams are of wrought iron, $2\frac{1}{4}$ inches diameter, fixed in a line with the centre of the cylinders, as seen in the plan.

*Slide-bars.*—The slide-bars consist of two bars 3 inches wide on each side of the piston-rod; they are made of the best hammered iron, and lined on the working faces with steel.

*Cross-heads.*—The cross-heads are made of the best hammered iron, and are firmly fixed to the piston-rods by means of cotters. The centre-pins which receive the small ends of the connecting rods are shrunk on.

*Connecting rods.*—The connecting rods are made of the best malleable iron, the smaller ends having brasses bored to 3 inches diameter, and the larger or 'crank-pin' ends bored to $4\frac{1}{2}$ inches diameter: the brasses are of the best metal, accurately fitted, and secured in their positions by means of cotters, as shown.

*Eccentrics.*—The eccentrics are fixed to the boss of the driving wheels.

*Valve Motion.*—The valve motion is that known as the 'link motion:' the blocks which work in the links or quadrants, as well as the various parts subject to wear, are case-hardened: the whole of the motion and levers are made of the best hammered iron.

*Buffers.*—The buffers are of leather, well stuffed with curled horse-hair, and are firmly secured to the front plate or 'buffer-beam' of the engine: the distance between the centres of the buffers, transversely, is 5 feet 8 inches, and the height from the level of the rails to the centres 3 feet 3 inches. The buffers are fitted with a guide spindle, which works in a bush in the buffer-beam.

*Foot-plate and Hand-rail.*—The foot-plates are 6 inches wide and $\frac{5}{16}$ inch thick, and made of the best Staffordshire iron; they are bolted to the outside framing, and extend nearly the whole length of the engine, as best seen on the plan. The hand-rails are hollow, through one of which the rod which communicates motion to the damper fixed in the smoke-box passes.

*Felting, &c.*—The barrel of the boiler, cylinders, and branch steam-pipes are covered with a coating of No. 3 hair felt, lagged with timber, and lined over all with sheet iron of the thickness of No. 17 wire-gauge, firmly secured with proper hoops, bolts, and nuts. The outside of the fire-box is also covered with felt, and lined with sheet iron of the same thickness as that covering the barrel of the boiler.

There are syphons, syphon-tubes, pet-cocks for the pumps, glass gauges, whistle, drag-links, &c., made of the best materials.

The whole of those parts of the engine which are not left bright are painted with three coats of the best mineral paint, and finished with a coat of the best copal varnish.

END OF VOL. I.

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